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PINTATURPEEN VILJAVUUSTUNNUKSET SUHTEESSA KASVUPAIKKATYYPPIIN JA PUUSTON KASVUPOTENTIAALIIN

Carl Johan Westman

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CARL JOHAN WESTMAN

SELOSTE:

PINTATURPEEN VILJAVUUSTUNNUKSET SUHTEESSA KASVUPAIKKATYYPPIIN JA PUUSTON KASVUPOTENTIAALIIN

To be presented, with the permission of the Faculty of Agriculture
and Forestry of the University of Helsinki, for public criticism
in Auditorium II of Metsätalo, Unioninkatu 40 B, on 9 May 1981
at 10 o'clock a.m.

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PREFACE

The present study constitutes the basic part of an investigation on the relationship between soil properties and ground vegetation – tree stand productivity carried out in the Department of Silviculture, University of Helsinki, during the period of time beginning in the year 1973. I am deeply indebted to, Professor Paavo Yli-Vakkuri, former Head of the Department, for his kindness in placing research facilities at my disposal and supporting me during the course of this research. The recent Head of the Department, Professor Matti Leikola, has kindly guaranteed the continuity of this support.

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Mrs. Pirjo Ahdekivi translated my manuscript from Swedish into English and I wish to thank her for her work. I am also indebted to Mrs. Aune Koponen, M. Sc., who checked the botanical terminology.

The laboratory analyses included in this study were performed by Mr. Pentti Pölönen, Mrs. Marja Ulpovaara-Greenlees and Miss Merja Jaakkola.

During the initiation of this investigation I received a travel grant from Suomen Kulttuurirahasto, enabling a trip to research institutions in Norway and Sweden, were I had the possibility to obtain valuable information from Professors Oddvar Haveraaen, Hilmar Holmen and Boris Meshechok.

Financial support for this investigation has been received from Kemira Oy Säätiö, Svenska Kulturfonden, The Finnish Academy of Science and Letter as well as the Society of Forestry in Finland, which also accepted the study for publication in its series.

Helsinki March 1981

C. J. WESTMAN.

CONTENTS

1 INTRODUCTION

11. Site type classification and timber production capacity in relation to physical and chemical properties of soil

Variations in the ground vegetation and productivity of sites belonging to a relatively uniform climatic region are mainly determined by the direct growth factors, and primarily by the availability of water and nutrients in the soil (cf. FIEDLER et al. 1973). A site type classification based on measuring the various growth factors must thus, to a hight degree, reflect the influence of these two factors. Efforts to explain differences in stand growth from the point of view of soil properties were done with some success already by SCHÜTZE (1871) and von FALKENSTEIN (1912). Site classification in Finland was seen in a new light after CAJANDER (1909, 1913) had introduced his theories concerning forest site types/peatland site types. Indeed, the concept of site type was soon considered to be a satisfactory measure for site quality. In addition, on this basis it was possible to group sites for more detailed examination. VALMARI (1921) studied soil chemical properties of a number of site types, and when the analysis values were grouped according to the Cajanderian forest site types, a reasonable relationship could be shown with the ignition loss, the total amount of electrolytes as well as with the amounts of calcium oxide and nitrogen. ILVESSALO (1923) later related the above mentioned soil properties to the corresponding stand increment data and among the macronutrients found the following correlations with increment in pine stands:

nitrogen	N	r=0.607±0.085
calcium oxide	CaO	r=0.537±0.094

These studies were continued by AALTONEN (1926, 1929, 1937) and VIRO (1947, 1951), but without resulting in either a further development of the Cajanderian site types or in an alternative classification based on measurements of soil properties. URVAS and ERVIÖ (1974) have presented a summary of chemical and physical tests made from forest soil samples collected in connection with a national soil survey currently in progress. When grouping the research material by forest site type, a logical relationship was obtained with soil texture, nitrogen content, and with extractable nutrients (ammonium acetate, pH 4.65). However, the variation within the site types was considerable.

The studies mentioned concern mineral soils, but the site type classification has been applied also to peatland sites (CAJANDER 1913). Indeed the peatland site types, the number of which greatly outnumber mineral soil site types, have received considerable investigation. Studies regarding biology, forest productivity and drainage profitability have been made (e.g. LUKKALA 1929, 1937, VAHTERA 1955, HEIKURAINEN 1959, KELTIKANGAS & SEPPÄLÄ 1966, HUIKARI & PAARLAHTI 1967, SEPPÄLÄ 1968, 1969, PAARLAHTI et al. 1971). The emphasis of the above mentioned studies has been the utilization of peatlands for forestry, particularly in the regulation of soil water and its beneficial effects. The relationship between site type and the chemical properties of peat have been examined, but not as comprehensively as might be expected when considering the extent of forest drainage in Finland. By analysing the surface peat from 50-year old and younger forest drainage areas, VAHTERA (1955) was able to show a relatively good relationship between peatland site type and degree of acidity, as well as the total contents of nitrogen and calcium. However, it proved impossible to classify the sites included in the investigation on the basis of the soil data obtained. On the whole, similar results were obtained by HEIKURAINEN (1953) on eutrophic pine mires in north Finland and, under comparable circumstances, by HOLMEN (1964), HAVERAAEN (1969) and VALK (1973).

The above discussion concerns total contents of one or more of the nutrients: nitrogen, phosphorus, potassium, clacium and magnesium. The problem becomes rather more complicated if one tries to establish a relationship between extractable fractions of nutrients, i.e. plant available nutrients in peat, and site quality. HOLMEN (1964) found a tendency towards negative relationships between ammonium lactate extractable phosphorus and potassium in peat and stand characteristics. MANNERKOSKI (1973) also reports a comparable result when using acid ammonium acetate (pH 4.65) as an extractant. PAARLAHTI et al. (1971) found weak correlations between stand growth and ammonium acetate (pH 4.65) extractable macronutrients in the surface peat, but no correlations with the fractions extractable in hot 2-N hydrochloric acid. STARR and WESTMAN (1978) observed after extracting with 0.05-N sulfuric acid a tendency towards a relationship between site type and the nutrient levels of the peat, in particular when expressing the analysis results in absolute amounts, i.e. kilograms of nutrient per hectare.

When assessing the fertility of a site one must also bear in mind the supply of micronutrients. HUIKARI (1974) suggests that tree growth disturbances on certain drained peatlands are due to a lack of micronutrients. BRAEKKE (1977) points out that particularly boron and manganese deficiencies may result in serious growth disturbances; the symptoms of which have been described by RAITIO and RANTALA (1977).

To summarize, one can say that in the case of both mineral soils and organic soils the relationship between the chemical – physical properties of soil, the surface vegetation, and productivity of the site has not yet been sufficiently clarified. A contributory reason for this is surely the great heterogeneity of soil (e.g. GJEMS et al. 1967, TROEDSSON & TAMM 1969, TROEDSSON & LYFORD 1973 WESTMAN 1977). By analysing a large number of samples one can arrive at average values of soil properties which satisfactorily agree with site quality index classifications. Even so, the variation within a site quality class is considerable and it is, therefore, difficult to locate an individual site at the appropriate point in a series of sites using only soil data. In mineral soils part of the variation can be attributed to soil texture, e.g. *Oxalis-Myrtillus* site type may appear on soils of quite different particle-size distribution (URVAS & ERVIÖ 1974). In case of organic soils difficulties have arisen from the comparisons being made between far too different site types. Sometimes even soil improvement measures such as drainage and fertilization have been included in studies, and this has surely increased variation. The importance of the choice of analytical method must not be underestimated either, particularly if different extracting methods are used.

12. Aims and general outline of the study

The aim of this study is to clarify the relationship between soil fertility and the timber production capacity of a number of Finnish peatland site types defined by a vegetation continuum. The connection between the concept of site type and the physical and chemical properties of the substrate is established. External habitat factors affecting within site type variation of soil properties are examined. Finally a predictive mathematical model is derived to explain site quality index on the basis of soil data.

Some of the problems arisen in investigations on the soil – vegetation – productivity relationships can be eliminated by using the concept forest site type/peatland site type (CAJANDER 1909, 1913). Peatland site types, by their great number compared to mineral soil site types, greatly facilitate the study of site fertility – vegetation interactions. Sensitivity to habitat conditions is already reflected in basic division of peatlands into treeless and tree covered sites classified by the dominant tree species. Further, throught the very definition of the peat forming process the physical and chemical properties of the substrate are determined by the composition and properties of the ground vegetation and vice versa.

Developing from the assumption that the ground vegetation and stand productivity of a site series within a relatively uniform climatic region are related to a hydrological and a nutrient gradient, it is possible to place the Cajanderian peatland site types in a two dimensional space defined by these two gradients (e.g. HEIKURAINEN 1972, 1979). Accordingly, one can in such a co-ordinate

system distinguish site series, the hydrology of which is rather uniform and which shows a continuous change in the amount of nutrients available in the substrate. One such group is made by the Scots pine (*Pinus sylvestris*) growing sedge mires, which includes the small sedge pine mire, the ordinary sedge pine mire and the herb-rich sedge pine mire.[1]

This series present a continuum in which the vegetation of the ground layer shifts from one that is relatively poor in species number and dominated by white mosses (*Sphagnum*) and sedges, to one with abundance of species including meso-eutrophic mosses as well as sedges, grasses and herbs. Productivity studies have also shown that the stand development on these sites after drainage, when the hydrological conditions are optimized or at least no longer the growth limiting, correlates well with the trophic status of these site types (LUKKALA & KOTILAINEN 1951, HEIKURAINEN 1959, 1979, HEIKURAINEN & HUIKARI 1960). By restricting the study to such a series it should be possible to clarify the relationship between growth of Scots pine and the nutrient status of soil.

A further reason for investigating the sedge mire series mentioned above is the fact that the nutrient content in peat from, in particular, the small sedge mires approaches the minimum requirement levels for tree growth. After drainage nutrient contents are at a premium and thus the relationships between stand development and the fertility of peat should be clear.

According to FIEDLER and NEBE (1963) and LENTSCHIG (1965) the quickmethods used in agricultural chemistry are less suitable for evaluating the nutrient status of forest soils. Since stand development stretches over a long period of time, the total nutrient content in soil is probably the better indicator for site fertility. In this respect peat soils offer a certain advantage compared to mineral soils. In peat the nutrients are bound or absorbed in organic forms, thus the relationship between total contents and plant supply through the mineralization can be expected even more direct than in mineral soils. Further, a pure peat sample is less complicated to analyse than a mineral soil sample as the former is comparable to plant material and the total content of nutrients can be obtained with relative ease.

The study at hand sets out from the hypothesis of a relationship between the nutrient content of surface peat and the species composition of the peat forming plant community. Which nutrients affect, or are being affected by, the surface vegetation is of particular interest. Physical properties such as the structure of the peat is of importance when examining the hydrology of organic soils (cf. PÄIVÄNEN 1973). However, the hydrology of organic soils is beyond the scope of this study and, actually, the site types included theoretically do not in this respect differ from each other. On the other hand, through the mere nature of the peat forming process the physical properties of the organic matter are subjected to a continuous change and may show certain site dependence. Thus relationships between such soil properties and site type cannot be excluded despite the hydrological uniformity within the site series and will be taken into account in the study.

Within site type relationships between the various soil properties will be discussed. In cases with logical correlations, the independent variable will be used as a covariate when evaluating the relationship between the dependent soil habitat and the site type. In addition within site type variation in soil properties can arise from fully independent external factors such as microtopography of the mire plane[2], depth of the peat layer and geographic factors. In particular mineralogy of underlying bedrock and mineral soil as well as macroclimate can be considered important. Influence of the former can possibly be seen in the regional occurence of various site types. Variations in the climate are expressed in the regional peatland complexes described by RUUHIJÄRVI (1960) and EUROLA (1962). On the contrary, among the peatland site types no climate dependent differentiation can be seen as is the case with the mineral soil site types (cf. CAJANDER 1949, LEHTO 1969). This is somewhat confusing since the biological

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[1] The concept sedge mire has been used for the vegetation associations studied and parallels the concept pine swamp (see HEIKURAINEN 1972, 1979). To simplify, the sedge pine mires studied will here after be retered to as sedge mires.

[2] i.e. the flat surface between hummocks and hollows, which forms the majority of the mire area.

decomposition processes in organogenic soils are more or less climate dependent. As a consequence the decomposition of organic matter and thereby particularly nutrient mineralization are considerably slower in north Finland than in the south (cf. MIKOLA 1960, LÄHDE 1974). In particular the nitrogen economy creates an increasing limiting growth factor along with less favourable climate (ANTTINEN 1951, SALONEN 1958, PESSI 1966, MÖLLER 1971, SEPPÄLÄ & WESTMAN 1976).

When examining the processes on the basis of the composition of the plant community, i.e. the nutrient balance of soil under comparable vegetation types, the following relation to macroclimate is conceivable. Under favourable climatic conditions nutrient mineralization is faster than under less favourable conditions. As a consequence, a smaller amount of nutrients can be expected sufficient for supplying a nutrient cycle satisfying the needs of the plants. On the other hand, a constant nutrien uptake by a similar type of ground vegetation under less favourable climatic conditions requires higher nutrient amounts in the substrate.

Converting the soil nutrient contents into absolute amounts on the basis of bulk density data creates a basis for evaluating the conditions for continuous timber production on the sites studied. The difficulty in this study is to produce stand data for comparisons. Due to excess water, the tree stand on the virgin peatlands in question is very sparse. The basic assumtion in this investigation is that the nutrient supply in soil is decisive for stand development only after the regulation of soil water. As it is thus not possible to procure any specific data for post drainage growth on the single sample plot, the site quality index by HEIKURAINEN (1973a) will be taken to illustrate the mean timber production potential of the virgin sites.

2 MATERIAL AND METHODS

21. Sample plots

The research material was collected from a number of virgin sedge mires from all over the country (Figure 1). In north Finland, peatland areas were preliminary selected on the basis of a map-based reconnaissance of regions rich in peatlands. In central and south Finland known peatland preservation areas as well as areas to be drained in 1975–76 were preliminarily selected. During the field sampling, carried out in summers of 1974 and 1975, the areas were systematically checked. Altogether 51 sedge mires in virgin conditions were accepted and classifield according to CAJANDER (1913) and HEIKURAINEN (1968). In these areas 168 temporary sampling points were randomly laid out. An additional 30 sample points are included, selected randomly from amongst 200 permanent sample points on two fairly uniform sedge mires, a herb-rich and an ordinary sedge mire (see WESTMAN 1977). The sample points are distributed between the tree site types as follows:

Herb-rich sedge mire	47	points
Ordinary sedge mire	107	”
Small sedge mire	44	”

In addition to the general site classification, a detailed description of the ground vegetation from a 0.5 m² circular area surrounding the sampling point was made. Percentage cover of each species present was estimated. Using the sample point as a centre for a relascope sample plot, the basal area of each tree species present was measured. In the relascope sample plot the diameter at breast height ($d_{1.3}$) and the height (h) of one dominant tree was recorded. Corresponding data was obtained for the randomly chosen permanent sample points although the ground vegetation in this case was described from 1 × 1 m quadrats.

It is beyond the aim of this investigation to go into detail regarding the plant sociological observations. However, to give a general view of the ground vegetation of the site types studied, the mean percentage coverage and frequency of the plant species within the three peatland site types are presented in Table 1. The nomenclature applied follows that of HÄMET-AHTI et al. (1977) and KOPONEN et al. (1977). As the composition of the ground vegetation within the site type may vary according to the prevailing macroclimate the sample plots were divided into two climatic regions using the annual accumulative temperature of 1 050 degree days for allocation (cf. KOIVISTO 1970, HEIKURAINEN and SEPPÄLÄ 1973).

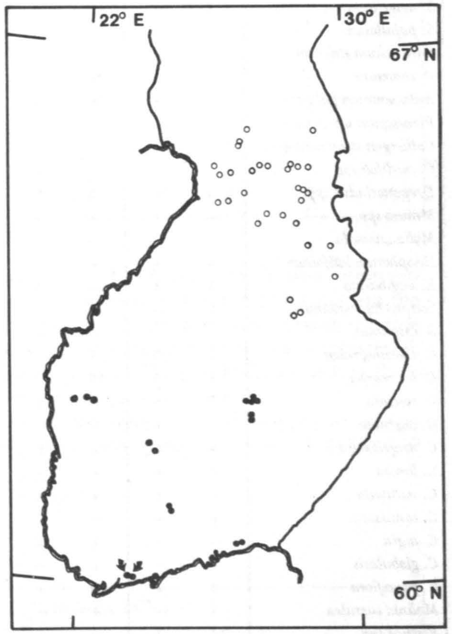

Figure 1. Location of the peatland areas studied. Filled circles indicates sites with annual accumulative temperature higher than 1050 degree days, open circles sites of 1050 degree days or less. The two areas marked with arrows have been used for intensive studies on peat heterogeneity (Westman 1977); the additional sample points mentioned in text originate from these.

Table 1. Species composition of the ground vegetation on the sites studied. Data is given for two climatic regions, the annual accumulative temperature of 1050 degree days is used for allocation of the sample plots, N = the northern region and S = the southern region.

Species	Mean coverage, per cent						Fequency, per cent					
	Herb-rich sedge mire		Ordinary sedge mire		Small sedge mire		Herb-rich sedge mire		Ordinary sedge mire		Small sedge mire	
	N	S	N	S	N	S	N	S	N	S	N	S
Sphagnum warnstorfii	6	–	–	–	–	–	14	–	–	–	–	–
S. subsecundum	+	+	+	–	–	–	14	29	4	–	–	–
S. girgensohnii	1	–	–	–	–	–	14	–	–	–	–	–
S. riparium	4	6	–	+	–	–	29	38	–	3	–	–
S. "recurvum" 1)	60	60	60	68	40	46	86	100	98	100	91	87
S. lindbergii	–	–	–	–	2	–	–	–	–	–	12	–
S. cuspidatum	–	–	5	6	22	30	–	–	27	32	37	62
S. rubellum	–	–	–	–	1	–	–	–	–	–	9	–
S. russowii	11	3	4	4	5	–	71	15	29	17	15	–
S. fuscum	–	–	2	+	14	4	–	–	7	3	44	12
S. magellanicum	2	2	12	5	4	10	29	5	68	33	15	37
S. papillosum	4	15	11	9	4	8	29	46	39	25	15	37
Polytrichum strictum	–	+	–	1	1	–	–	3	–	22	12	–
P. commune	–	2	+	+	–	–	–	18	16	7	–	–
Aulacomnium palustre	+	+	+	1	–	–	14	9	2	8	–	–
Pleurozium schreberi	–	–	–	+	1	–	–	–	–	8	6	–
Calliergon stramineum	+	+	+	+	–	–	14	15	7	5	–	–
C. cordifolium	–	–	–	+	–	–	–	–	–	3	–	–
Drepanocladus spp.	+	+	3	–	+	1	14	3	9	–	3	1
Mnium spp.	–	+	+	–	–	–	–	3	7	–	–	–
Mylia anomala	–	–	+	+	+	+	–	–	2	2	6	12
Eriophorum latifolium	+	+	+	+	–	–	14	3	7	3	–	–
E. vaginatum	1	8	10	18	10	25	14	51	79	80	82	87
Scirpus hudsonianus	1	–	–	–	–	–	14	–	–	–	–	–
S. cespitosus	–	–	+	–	5	2	–	–	11	–	32	12
C. chordhorrhiza	7	3	2	+	–	–	57	20	14	3	–	–
C. lasiocarpa	1	15	15	13	–	+	43	69	68	68	–	–
C. rostrata	7	5	6	14	+	+	43	51	52	53	6	12
C. vaginata	–	+	–	–	–	–	–	3	–	–	–	–
C. magellanica	+	+	+	+	+	–	15	3	9	2	6	–
C. limosa	+	+	+	+	1	–	14	3	14	3	15	–
C. ecchinata	+	+	+	+	–	–	14	23	2	3	–	–
C. cannescens	+	–	–	–	–	–	14	–	–	–	–	–
C. nigra	–	+	+	2	–	+	–	15	7	8	–	12
C. globularis	–	–	+	–	+	–	–	–	7	–	3	–
C. pauciflora	4	+	10	+	6	+	57	3	70	8	56	12
Molinia caerulea	1	–	+	–	–	–	14	–	2	–	–	–
Festuca spp.	1	1	–	+	–	–	3	2	–	5	–	–
Melampyrum spp.	–	+	+	+	–	–	–	8	2	3	–	–
Calamagrostis spp.	+	+	+	–	–	–	8	14	3	–	–	–
Selaginella selaginoides	+	–	–	–	–	–	14	–	–	–	–	–
Equisetum palustre	5	–	+	–	–	–	57	–	2	–	–	–
E. fluviatile	3	5	+	+	–	–	71	67	14	10	–	–
Scheuchzeria palustris	+	–	+	+	6	4	14	–	18	8	32	25
Dactylorhiza spp.	–	–	–	+	–	–	–	–	–	2	–	–

1) *angustifolium* and others.

Table 1. Continue.

Species	Mean coverage, per cent						Fequency, per cent					
	Herb-rich sedge mire		Ordinary sedge mire		Small sedge mire		Herb-rich sedge mire		Ordinary sedge mire		Small sedge mire	
	N	S	N	S	N	S	N	S	N	S	N	S
Hammarbya paludosa	–	+	–	–	–	–	–	3	–	–	–	–
Drosera spp.	+	+	+	+	+	2	29	5	16	5	50	12
Potentilla erecta	1	1	–	–	–	–	14	3	–	–	–	–
P. palustris	7	5	–	–	–	–	43	31	–	–	–	–
Rubus chamaemorus	+	+	1	3	7	6	57	3	11	22	47	62
Epilobium palustre	–	+	–	–	–	–	–	15	–	–	–	–
Trientalis europaea	+	+	–	+	–	–	14	5	–	2	–	–
Menyanthes trifoliata	19	26	5	3	–	2	71	87	32	15	–	12
Viola palustris	+	+	–	+	–	–	14	15	–	2	–	–
Peucedanum palustre	–	+	–	1	–	–	–	26	–	–	–	–
Betula nana	5	+	8	5	2	–	57	3	75	38	44	–
Calluna vulgaris	–	–	+	–	1	–	–	–	2	–	3	–
Vaccinum uliginosum	+	+	1	3	5	–	14	3	18	22	41	–
V. myrtillus	–	+	–	–	–	–	–	10	–	–	–	–
V. vitis-idaea	+	+	–	+	+	–	14	26	–	3	3	–
V. occycoccos & microcarpon	14	8	11	18	7	27	100	79	91	83	100	62
Andromeda polifolia	5	+	10	9	9	17	86	8	93	55	91	100
Ledum palustre	1	+	+	3	+	–	29	10	7	20	15	–
Empetrum nigrum	–	+	+	2	7	3	–	3	7	17	44	12
Chamedaphne calyculata	–	+	+	+	–	4	–	5	9	7	–	37

The mean basal area by tree species of the sample plots has been calculated (Table 2). The average breast height diameter and height of the dominant trees are given in Table 3. Evidently, the tree stand on the sites studied prior to regulation of soil water by drainage is quite sparse.

In addition to the above mentioned plant sociological observations, the depth of the peat deposit was determined to a maximum of 1.5 m, and it was observed whether the sample point was located on the mire plane[1] or on a clearly distinguishable hummock, the height of which was registered. Sample points falling on hollows such as flarks were systematically rejected.

From the centre of each temporary sampling plot two peat samples of 0.75 dm^3

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[1] See Page 7.

Table 2. Mean basal area of the tree stand on the sample plots.

Site type	Basal area, m^2/ha			
	Pine1)	Spruce2)	Birch3)	Total
Herb-rich sedge mire	6.3±0.8	0.8±0.2	6.0±0.7	13.1±1.3
Ordinary sedge mire	1.9±0.3	Δ	0.7±0.3	2.7±0.5
Small sedge mire	0.6±0.2	Δ	–	0.7±0.2

1) *Pinus sylvestris*

2) Picea abies (L.) Karst.

3) *Betula pubescens* and other hardwoods

Table 3. Properties of the dominant tree as well as mean basal area of the tree stand on sample plots were the dominant trees (tree stand) occure.

Tree species1)	Diameter at breast height, cm	Height, cm	Basal area, m^2/ha	Number of plots, per cent
	Herb-rich sedge mire			
Pine	12.2±0.7	8.4±0.4	10.9±0.1	69
Spruce	–	–	1.7±0.1	–
Birch	11.1±1.9	9.0±0.9	15.8±0.1	22
	Ordinany sedge mire			
Pine	8.9±0.7	5.7±0.3	4.7±0.1	55
Spruce	–	–	–	–
Birch	10.0±0.6	7.7±1.3	12.3±0.1	3
	Small sedge mire			
Pine	8.8±0.9	5.7±0.5	3.8±0.1	31
Spruce	3.0	4.0	<0.5	2
Birch	–	–	–	–

1) see table 2.

volume each were taken from the layers: 0–10 and 10–12 cm. The samples were extracted with a slightly conical cylinder having a saw-toothed cutting edge, and placed in polythene bags. The sealed bags were kept unfrozen for one to five days during the field working period, whereafter these were frozen (–20°C) to await further sample treatment.

22. Chemical and physical analyses

Laboratory treatment of the material began with weighing the frozen peat samples. Afterwards they were dried in an aerated oven at a temperature of 25–30°C, re-weighed and milled using a hammer mill fitted with a ø 2 mm bottom sieve. The remaining moisture content was determined by drying 5–10 g sub-samples for two hours at a temperature of 105°C. On the basis of these weighings the bulk density as well as the fresh weight and the water content at the time of sampling could be calculated.

The ash content was determined by ashing at ca 250°C and thereafter igniting at 550°C for two hours.

In order to define the degree of decomposition the volume weight of organic matter was determined according to P'YAVCHENKO (1958):

$$d_1 = \frac{d \times (100 - w) \times (100 - a)}{10\,000}$$

d = density of homogenized sample under pressure (1 kp/cm^2)
w = water content (per cent)
a = ash content (per cent)
d_1 = volume weight of organic matter, (g/cm^3)

Converting this value into a humification percentage has not been deemed necessary, as this would only mean including average coefficients dependent upon the peat type.

The degree of acidity and electric conductivity were determined from a 1:2.5 (V/V) peat-water suspension according to VUORINEN and MÄKITIE (1955). The pH of the suspension was measured with a double glass electrode after standing for 24 hours. The electric conductivity was measured from the same suspension and expressed in microsiemens centimetre (μS·cm).

The effective cation exchange capacity was determined by extracting a 4 g sample with 200 ml 1-N KCl (cf. KAILA 1971, NÖMMIK 1974). From aliquots, calcium and magnesium were determined by titration with NaEDTA and hydrogen and aluminium by titration with sodium hydroxide (HEALD 1965, McLEAN 1965), the sum of these ions expressing the effective cation exchange capacity of peat. Base saturation was calculated by expressing the proportion of calcium plus magnesium ions as percentage of the total effective cation exchange capacity.

The nitrogen content was determined by the macro Kjeldahl method. In the digestion a catalyst mixture of Na_2SO_4 and Se, 133 mg and 0.83 mg respectively per millilitre added H_2SO_4 was used. Ammonium nitrogen was distilled from the diluted digest in a modified Parnas-Wagner apparatus, and the distillate titrated with 0.01-N H_2SO_4 (BREMNER 1965).

The contents of total phosphorus, potassium, calcium and magnesium were determined by a somewhat simplified analysis for plant material. A peat sample was ashed and ignited as above, and the residue dissoloved in hot 0.5-N HCl upon a water bath. From this solution were determined phosphorus with the molybdenum-blue method (KAILA 1955), potassium photometrically with an EEL flame photometer, and calcium and magnesium using atomic absorption spectrophotometry (PERKIN-ELMER AA 303).

23. Statistical methods and computations

To establish the relationship between the site types studied and soil properties in question the material was firstly divided according to site type and peat layer; mean values and standard errors were then calculated. The stratified material was subjected to a two-way analysis of variance. In the cases where the variation between the classes formed was statistically significant, the mean values were compared in pairs by a Student-Newman-Keul's test. In a few cases one-way analysis of variance and t-test only were applied (SNEDECOR & COCHRAN 1968, SOKAL & ROHLF 1973, MÄKINEN 1974).

Due to the non-normal distribution within the classes, the variables were in several cases transformed prior to statistical testing, the most usual transformation being a logarithmic transformation and in a minor number of cases a square root transformation. An additional effect of the transformations was that the within class variance was made practically independent of the magnitude of the mean. When deciding about the transformations, checking of frequency diagrams was supported by calculating variation coefficients and testing the variances in pairs (SNEDECOR & COCHRAN 1968, WEBSTER 1977).

The results of these statistical tests are marked in the mean value tables with letter combinations as follows: Values not differing from each other at 5 % risk level are marked with the same letter. The comparison is made in pairs, proceeding from the value marked with an underlined letter.

The general relationship between the variables studied is shown by the help of simple correlation analysis. In cases with logically meaningful correlations, the regression model is calculated and the independent variable is used as a co-variate in the above described analysis of variance of the dependent variable. External factors affecting soil properties were checked partly by further classifying of the material prior to analysis of variance and partly by simple correlation and regression analysis (SNEDECOR & COCHRAN 1968, KORHONEN 1978).

The relationship between soil fertility and timber production capacity of the sites was studied by transforming the concept of site type, which in the first place is a classifying discrete variable, into a continuous index as follows (HEIKURAINEN 1973a).

$$\text{Site quality index} = \frac{v_i \times a_i}{1\,000}$$

where
v_i = fertility index
a_i = locality index.

The following fertility indices (v_i) were applied for the site types included:

Herb-rich sedge mire	70
Ordinary sedge mire	50
Eriophorum vaginatum sedge mire[1]	40
Small sedge mire	30

---

[1] Only a minor number of sites which usually were incorporated in the class ordinary sedge mire.

The locality index (a_i) for the single sample plot was calculated by inserting in the following formula (HEIKURAINEN & SEPPÄLÄ 1973) the annual accumulative temperature as independent variable:

$$\log Y = -0.4148 + 0.00321X - 10.47 \times 10^{-7}X^2$$
$$R^2 = 0.527.$$

The procedure differs from the one suggested by Heikurainen (1973a) so that the formula used does not give the general relationship between relative increment and macroclimate, but is specific for pine growing peatlands. The motive for this is that the dominant tree species on the sites in question is pine.

Firstly, the relationships between the site quality index and the absolute amount of each macronutrient was established. Finally, a multiple regression model (SNEDECOR & COCHRAN 1968, KORHONEN 1978)

$$Y = a_1X_1 + a_2X_2 \ldots + a_nX_n + C$$

was derived with the site quality index as dependent variable (Y) and the absolute amounts of macronutrients and annual accumulative temperature as independent variables ($X_1 - X_n$). In checking the weight of each independent variable in the model, simple correlation and partial correlation analysis was used (SNEDECOR & COCHRAN 1968).

In practice, the statistical analyses were performed with library programmes provided by the Computing Center of the University of Helsinki (HYLK/HYLPS 1977, KORHONEN 1978).

3 RESULTS AND DISCUSSION

31. Physical and chemical properties of the surface peat from the site types studied

31.1 Variables and the relationships between them

In this study the following soil properties are measured and will de discussed:

Bulk density, volume weight of organic matter, ash content, acidity, electric conductivity, effective cation exchange capacity, degree of base saturation, total contents of nitrogen, phosphorus, potassium, calcium and magnesium.

The three first mentioned can bee seen as purely physical factors, while the nature of the others is more or less chemical.

Before going into a detailed examination of the individual variables and their site dependence, it is advisable to discuss the relationship between them. The simple correlation coefficients calculated layerwise (0–10 cm and 10–20 cm) for the entire material are presented in Table 4. In a number of cases there are significant and even strong correlations, some of which were expected. For example, the correlations between calcium and magnesium contents, calcium content and acidity as well as degree of base saturation, bulk density and volume weight of organic matter can be explained by analytical factors or general chemical and mineralogical relationships. In addition both the bulk density and the volume weight of organic matter are correlated with nutrient contents and cation exchange capacity of peat. These correlations for the cation exchange capacity and potassium content are negative, while they are positive in the other cases. Considering that the data for the nutrients forming the basis for the correlation matrices are concentration values (mg/g), these relationships are of particular interest and probably due to differences in the humus matter forming the peat.

In this study it is hypotized that there exists some form of dependence between site type

Table 4. Simple correlations between the soil variables primarly measured.

Correlations in the 0–10 cm layer, n=192 Correlations in the 10–20 cm layer, n=165	Bulk density	Vol.w. org. matter	Ash content	pH	Electric cond.	C.E.C.	Base saturation	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Bulk density		0.42	0.31	0.09	0.29	−0.42	0.35	0.62	0.45	−0.64	0.26	0.18
Vol.w. org. matter	0.68		0.37	0.26	0.26	−0.04	0.19	0.59	0.43	−0.14	0.23	−0.04
Ash content	0.20	0.24		0.40	0.40	−0.05	0.39	0.61	0.42	−0.15	0.41	0.30
pH	0.16	0.17	0.47		0.29	0.46	0.35	0.37	0.27	0.24	0.50	0.48
Electric cond.	0.12	0.27	0.32	0.23		−0.09	0.49	0.38	0.40	0.00	0.46	0.42
C.E.C.	−0.52	−0.35	−0.10	0.16	−0.16		0.00	−0.25	−0.21	0.53	0.10	0.13
Base saturation	0.25	0.33	0.32	0.63	0.35	0.04		0.41	0.46	−0.19	0.81	0.68
Nitrogen	0.60	0.66	0.49	0.42	0.23	−0.26	0.42		0.62	−0.34	0.37	0.19
Phosphorus	0.41	0.45	0.47	0.26	0.37	−0.33	0.39	0.57		−0.16	0.45	0.36
Potassium	−0.35	−0.19	0.11	0.34	0.00	0.42	0.07	−0.06	−0.03		−0.10	0.01
Calcium	0.13	0.19	0.31	0.69	0.32	0.15	0.78	0.35	0.31	0.10		0.78
Magnesium	−0.07	0.09	0.29	0.53	0.39	0.16	0.56	0.12	0.21	0.15	0.72	

Table 5. Simple correlations between the soil variables primarily measured in peat from the herb-rich sedge mires.

Correlations in the 0–10 cm layer, n=46 Correlations in the 10–20 cm layer, n=26	Bulk density	Vol. w. org. matter	Ash content	pH	Electric cond.	C.E.C.	Base saturation	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Bulk density		0.19	0.23	0.31	0.30	−0.22	0.49	0.48	0.31	−0.60	0.24	0.23
Vol.w. org. matter	0.73		0.42	0.55	0.01	0.26	−0.17	0.53	0.39	0.13	0.27	−0.11
Ash content	−0.16	0.22		0.38	0.30	0.12	0.14	0.58	0.19	−0.01	0.05	−0.02
pH	0.08	0.09	0.16		0.37	0.60	0.07	0.56	0.50	0.29	0.59	0.41
Electric cond.	−0.26	−0.06	0.16	0.11		−0.01	0.20	0.36	0.14	0.02	0.12	0.25
C.E.C.	−0.29	−0.23	0.15	0.45	0.07		−0.26	−0.08	0.08	0.54	0.36	0.25
Base saturation	0.33	0.47	−0.46	0.48	−0.22	0.30		0.03	−0.14	−0.48	0.47	0.33
Nitrogen	0.39	0.38	0.30	0.19	−0.01	0.10	0.02		0.46	−0.16	0.14	−0.02
Phosphorus	−0.35	−0.35	0.05	−0.43	−0.10	−0.17	−0.49	0.14		0.16	0.09	0.24
Potassium	−0.57	−0.56	0.29	0.23	0.14	0.34	−0.23	−0.13	0.08		0.13	0.15
Calcium	−0.10	−0.05	−0.23	0.66	−0.06	0.65	0.63	0.07	−0.33	0.16		0.57
Magnesium	−0.44	−0.37	0.04	0.25	0.24	0.58	0.28	0.04	0.03	0.20	0.53	

Table 6. Simple correlations between the soil variables primarily measured in peat from the ordinary sedge mires.

Correlations in the 0–10 cm layer, n=104 Correlations in the 10–20 cm layer, n=96	Bulk density	Vol. w. org. matter	Ash content	pH	Electric cond.	C.E.C.	Base saturation	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Bulk density		0.34	0.13	−0.16	−0.12	−0.60	−0.04	0.55	0.40	−0.65	−0.10	−0.10
Vol.w. org. matter	0.50		0.27	−0.01	0.20	−0.19	0.05	0.60	0.40	−0.17	0.14	−0.25
Ash content	0.19	0.32		0.44	−0.04	0.07	0.19	0.47	0.22	−0.11	0.23	0.13
pH	0.07	0.13	0.46		−0.01	0.47	0.40	0.18	0.03	0.24	0.51	0.48
Electric cond.	0.10	0.28	0.32	0.11		−0.02	0.14	−0.08	0.01	0.21	0.23	0.12
C.E.C.	−0.54	−0.24	0.00	0.21	−0.15		0.23	−0.27	−0.24	0.51	0.25	0.27
Base saturation	0.07	0.20	0.29	0.52	0.33	0.04		0.16	0.18	−0.03	0.75	0.58
Nitrogen	0.51	0.62	0.53	0.37	0.11	−0.23	0.32		0.54	−0.41	0.12	−0.06
Phosphorus	−0.51	0.57	0.42	0.17	0.23	−0.26	0.24	0.53		−0.25	0.20	0.05
Potassium	−0.28	−0.01	0.17	0.40	−0.07	0.39	0.12	0.04	−0.07		−0.04	0.10
Calcium	−0.07	0.05	0.28	0.60	0.31	0.27	0.72	0.16	0.14	0.14		0.77
Magnesium	−0.13	−0.23	0.23	0.51	0.35	0.17	0.54	−0.04	−0.02	0.17	0.72	

and edaphic growth factors. One may therefore assume that relationships between the individual soil properties and the site type affect the correlation coefficients given in Table 4. If the same correlations calculated separately for each site type (Tables 5, 6, 7) are different from the overall correlations (Table 4), dependence upon site type is indicated. However, a detailed examination of these correlations will be presented when discussing the single variables in the following.

31.2 Bulk density and degree of decomposition

In this investigation the bulk density as well as the fresh weight of peat at the time of sampling were determined. The bulk densities in the 0–10 cm layer vary between 15 and 152 g/dm^3 and in the 10–20 cm layer between 25 and 158 g/dm^3 (Figure 2). PÄIVÄNEN (1973) presents for slightly to medium humified *Sphagnum* and *Carex* peat bulk densities from 0.037 to 0.113 g/cm^3 and from 0,054 to 0.141 g/cm^3, respectively. In comparison with these values, the smallest bulk densities obtained in this investigation are somewhat lower. This is explained by the fact that living plant material was included in the samples which reduces the bulk density, in particular, in the upper layer. The highest isolated values (Figure 2) can be attributed to the inclusion of wood remains in these samples. The mean values calculated by site type

Table 7. Simple correlations between the soil variables primarily measured in peat from the small sedge mires.

Correlations in the 0–10 cm layer, n=42 Correlations in the 10–20 cm layer n=43	Bulk density	Vol.w. org. matter	Ash content	pH	Electric cond.	C.E.C.	Base saturation	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Bulk density		0.64	0.05	−0.29	0.07	−0.22	0.05	0.66	0.44	−0.52	−0.09	−0.48
Vol.w. of org. matter	0.87		0.02	−0.26	0.53	0.10	0.12	0.50	0.43	−0.26	0.05	−0.32
Ash content	−0.11	−0.13		0.14	0.48	−0.31	0.09	0.28	0.08	−0.09	0.13	0.00
pH	−0.33	−0.32	0.14		0.06	0.60	0.38	0.00	−0.37	0.55	0.30	0.41
Electric cond.	0.18	0.27	−0.15	−0.01		0.20	0.13	0.10	0.30	0.27	0.11	0.07
C.E.C.	−0.51	−0.47	−0.38	0.42	−0.20		0.21	−0.15	−0.27	0.59	0.15	0.35
Base saturation	−0.02	−0.01	0.06	0.49	−0.18	0.04		0.04	0.14	0.22	0.71	0.52
Nitrogen	0.70	0.70	−0.02	−0.02	0.17	−0.34	0.10		0.43	−0.24	0.00	−0.28
Phosphorus	0.36	0.44	0.31	−0.29	0.24	−0.56	0.09	0.50		−0.21	0.14	−0.19
Potassium	−0.36	−0.32	−0.17	0.53	−0.28	0.63	0.08	−0.21	−0.33		0.10	0.46
Calcium	−0.18	−0.12	0.05	0.45	−0.15	0.18	0.60	0.03	−0.17	0.10		0.71
Magnesium	−0.35	−0.33	0.28	0.32	−0.02	0.24	0.32	−0.25	−0.23	0.05	0.67	

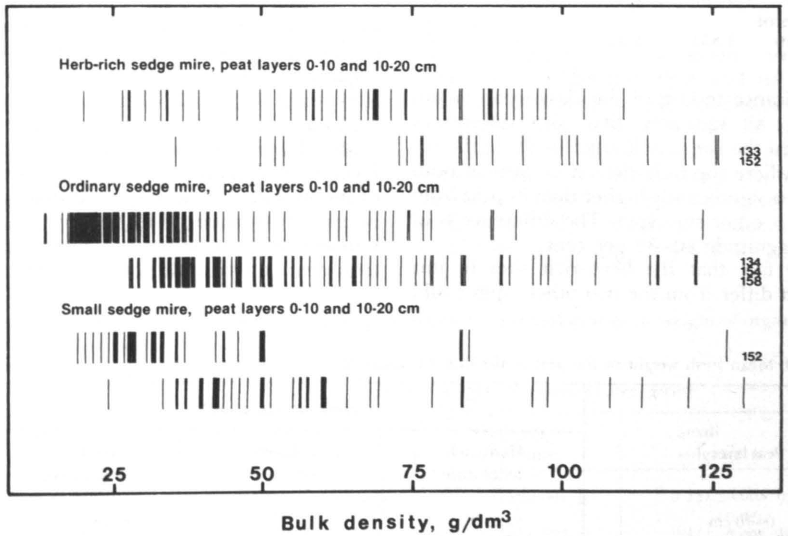

Figure 2. Bulk density of the peat samples.

Table 8. Mean bulk densities of the peat samples.

Peat layer	Bulk density, g/dm³		
	Herb-rich sedge mire	Ordinary sedge mire	Small sedge mire
0–10 cm	$61.5^{+3.9}_{-3.7}$ a	$32.2^{+1.4}_{-1.4}$ b	$36.6^{+2.7}_{-2.5}$ b
10–20 cm	$87.0^{+6.0}_{-5.6}$	$54.1^{+2.4}_{-2.3}$ a c	$55.3^{+3.3}_{-3.1}$ a c

and layer (Table 8) do not indicate any differences in comparison with PÄIVÄNEN's (1973) results. The data given by HOLMEN (1964) for corresponding sites are somewhat higher than those obtained here. The last mentioned study concerns, however, an old drained peatland area, where changed hydrological conditions and increased stand weight have affected the density of peat.

The logarithmically transformed bulk densities classified according to site type and layer were tested with a two-way analysis of variance, which shows significant variations between site types as well as peat layers:

	Model of variance	Between site types	Between layers	Interaction
F-value	36.65***	24.97***	34.54***	1.17
Degrees of freedom	5,351	4,351	3,351	2,351

Significance testing of the class mean values (Table 8) indicates that the differences between the sites are limited to the herb-rich sites, where the bulk density of peat in both layers is significantly higher than in peat from the two other site types. The difference is of the magnitude 60–80 per cent.

The fact that the herb-rich sites in this respect differ from the two other types could be attributed to a higher degree of humification as well as to a higher proportion of woody remains in the peat. On the basis of Tables 2 and 3 it can be established that the tree stand on the herb-rich sites is much better developed than that on the ordinary and small sedge mires.

Peat from the lower layer in all cases shows a significantly higher bulk density than that from the upper layer (cf. e.g. ISOTALO 1951). The magnitude of the increase varies between 40 and 70 per cent.

The mean fresh weight of peat at the time of sampling is shown in Table 9. The values vary in the 0–10 cm layer between 513 g/dm³ and 676 d/dm³ and in the 10–20 cm layer between 779 g/dm³ and 877 g/dm³, which is equivalent to a water content from 48 to 64 and from 72 to 79 volume percentage in the upper and lower layers, respectively. The high proportion of air-filled pores is surprising because of the high precipitation in the summer of 1974 (HEINO 1976, Meteorological Yearbook . . .). Most of the samples to be analysed were collected in August that year. From hydrological point of view this data is of minor value. However, when determining in particular extractable fractions of plant nutrients in peat, water loss due to sample treatment is a possible source of error.

Table 9. Mean fresh weight of the peat at the time of sampling.

Peat layer	Fresh weight, g/dm³		
	Herb-rich sedge mire	Ordinary sedge mire	Small sedge mire
0–10 cm	623±28	513±22	676±37
10–20 cm	877±24	779±15	843±20

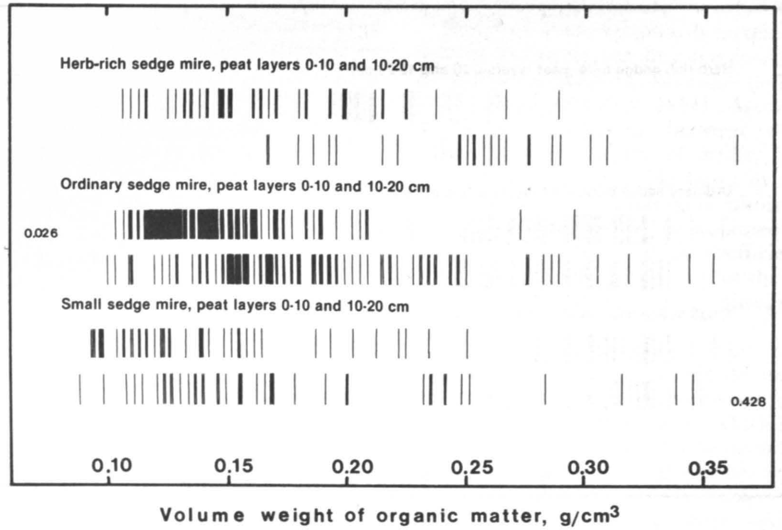

Figure 3. Degree of decomposition of the peat samples given as volume weight of organic matter (P'yavchenko 1958).

The degree of decomposition of peat was examined on the basis of the volume weight of organic matter. The values measured in the 0–10 layer range between 0.026 g/cm³ and 0.297 g/cm³ and in the 10–20 cm layer between 0.090 g/cm³ and 0.428 g/cm³ (Figure 3). The mean values calculated varied in the upper layer between 0.137 and 0.165 g/cm³ and in the deeper layer between 0.171 and 0.244 g/cm³ (Table 10), and agree with those presented by SARASTO (1960) for slightly and medium humified peat, 0.110 and 0.380 g/cm³.

After logarithmic transformation of the volume weight of organic matter differences between the classes were tested with a two-way analysis of variance:

	Model of variance	Between site types	Between layers	Interaction
F-value	21.87***	9.91***	28.08***	2.13
Degrees of freedom	5,342	4,342	3,342	2,342

There appears a significant variation between both the site types and the layers studied. Examination of the means shows similar differences between the site types as for the bulk density. Close agreement between the bulk density and the volume weight of organic matter is expected in organic soils of such low ash content (see ch. 31.3). However, the coefficients for the

Table 10. Mean degree of decomposition of the peat samples expressed as volume weight of organic matter (p'yavchenko 1958).

Peat layer	Volume weight of organic matter, g/cm³		
	Herb-rich sedge mire	Ordinary sedge mire	Small sedge mire
0–10 cm	0.165±0.006 a	0.143±0.004 b	0.137±0.006 b
10–20 cm	0.244±0.010	0.182±0.005 a c	$0.171^{+0.010}_{-0.009}$ a c

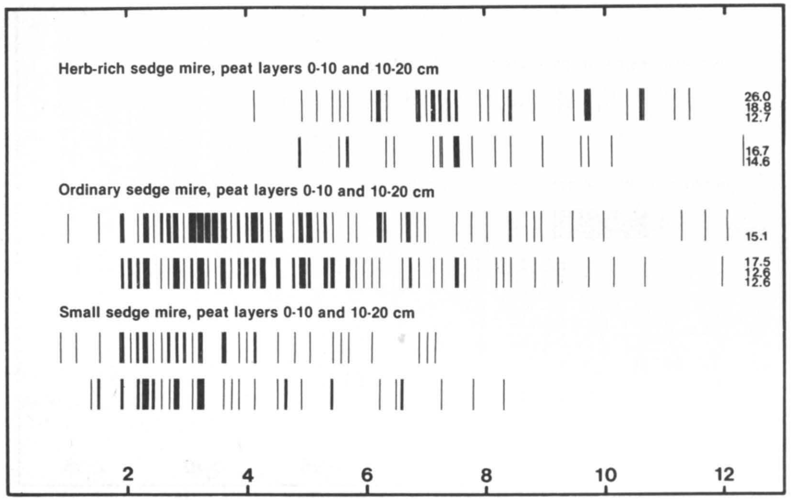

Figure 4. Ash content in the peat samples.

correlation between these two variables, calculated by layer for the entire material, are surprisingly low, 0.42*** and 0.68*** in the upper and lower layers (Table 4). This can be explained by the fact that most of the peat samples were slightly to medium humified and that the volume weight of organic matter is an artificial measure for the degree of decomposition. Consequently the bulk density of peat is a better overall variable, and will be used in the following when discussing the degree of decomposition of the peat.

31.3 Ash content

The ash content of peat varies in the 0–10 cm layer from 0.9 to 26.0 per cent and in the 10–20 cm layer from 1.4 to 17.5 per cent. According to the frequency diagrams, Figure 4, values exceeding 11–12 per cent can be considered extreme. The isolated ash content of 26 per cent refers to a site with a noted eutrophic ground vegetation. Analyses of micronutrients in this case show a very high content of iron. Other high ash data can probably be explained in a similar manner, i.e. an enrichment of nutrients by overland flow of water rich in minerals, which results in an eutrophic ground vegetation. Wood remains, which are rich in ash compared to *Carex* and *Sphagnum* peat components (e.g. PÄIVÄNEN 1973), may also have contributed to the high values.

The mean ash contents were calculated after classifying the material according to site type and peat layer (Table 11). The values range from 3.1 to 8.0 per cent in the 0–10 cm layer and from 3.3 to 7.9 per cent in the 10–20 cm layer and agree well with values given by PÄIVÄNEN (1973) for *Sphagnum, Carex* and woody peats, the mean ash content of these peat types being 3.0, 4.7 and 8.6 per cent, respectively. SARASTO (1960) also reports, by peat type, values of the same magnitude. Although the stratification in this study was done according to site type there is reason to assume that the composition of the peat formed by these plant communities corresponds to a shift from *Sphagnum-Carex* peat towards woody peat (cf. Tables 1–3).

Table 11. Mean ash content of the peat samples.

Peat layer	Ash content, per cent		
	Herb-rich sedge mire	Ordinary sedge mire	Small sedge mire
0–10 cm	$8.0\ ^{+0.39}_{-0.37}$ $\underline{a}$	$4.3\ ^{+0.21}_{-0.20}$ $\underline{b}$	$3.1\ ^{+0.23}_{-0.22}$ $\underline{c}$
10–20 cm	$7.9\ ^{+0.51}_{-0.48}$ a	$4.5\ ^{+0.23}_{-0.22}$ b	$3.3\ ^{+0.24}_{-0.23}$ c

VAHTERA (1955) found that the mean content of ash is 5.2 per cent in peat from ordinary sedge mires and 7.0 per cent in peat from herb-rich sedge mires, i.e. almost exactly the same values as obtained in this study. Peat from sites corresponding to small sedge mires had ash contents of more than eight per cent. This discrepancy is explained by secondary factors such as overland flow of surface water containing minerals. The explanation is somewhat peculiar as one would expect that the surplus of minerals would have an eutrophying effect on the surface vegetation.

A two-way analysis of variance after logarithmic transformation of the ash contents shows that there is no difference between the two peat layers but the variation between the site types is statistically significant:

	Model of variance	Between site types	Between layers	Inter-action
F-value	31.14***	38.89***	0.38	0.16
Degrees of freedom	5,342	4.342	3,342	2,342

Significance testing of the means (Table 11) shows that the ash content increases gradually in both the layers in the site series from the small sedge mires to the herb-rich sedge mires. The increase is between the two less fertile site types of the magnitude 35–40 per cent and between the two more fertile 75–85 per cent. Thus, the ash content is more than doubled from the small sedge mires to the herb-rich sedge mires.

This clear tendency towards increasing ash content is of interest as the ash is considered a guide to site quality (e.g. KIVINEN 1948, VAHTERA 1955, HOLMEN 1964). Accordingly, significant correlations between the ash content and the degree of acidity, electric conductivity, exchangeable bases as well as with the contents of nitrogen, phosphorus, calcium and magnesium are obtained (Table 4). However, in most cases the coefficients are rather low, exceeding 0.40 only for the degree of acidity and the contents of nitrogen and phosphorus.

The relationship between ash content and acidity can be expected as both the variables are overall factors reflecting the site fertility. Of the pure mineral elements, which should directly impinge on the ash content of the peat, only calcium in the upper layer gives a coefficient higher than 0.40 (Table 4). This result is somewhat surprising compared against the clear positive relationship between site quality and average ash content (Table 11), and the trends shown by the contents of calcium and magnesium in peat (see ch. 31.9, 31.10). On the other hand, the sum of the highest calcium and magnesium observations corresponds to an ash percentage not higher than 1.2.

The relatively strong correlations between ash content and contents of nitrogen and phosphorus, both of which are organically bound, deserves further attention. In the case of phosphorus the relationship may be a result of correlation between both the variables and site quality, which assumption is supported by the low coefficients in Tables 5–7. In the case of nitrogen the relationship seems much clearer. Even when calculating the correlation matrices separately for each site type (Tables 5–7) significant coefficients are obtained for the two more fertile site types.

31.4 Degree of acidity and electric conductivity

The pH in peat from the sites varies within rather a limited range, from pH 3.7 to 5.6 in the 0–10 cm layer and from pH 3.6 to 5.3 in the 10–20 cm layer (Figure 5), however, most of the observations are below pH 5.0. Corresponding to active acidity (SCHEFFER & SCHACHTSCHABEL 1976) the pH values found must be considered low, but are

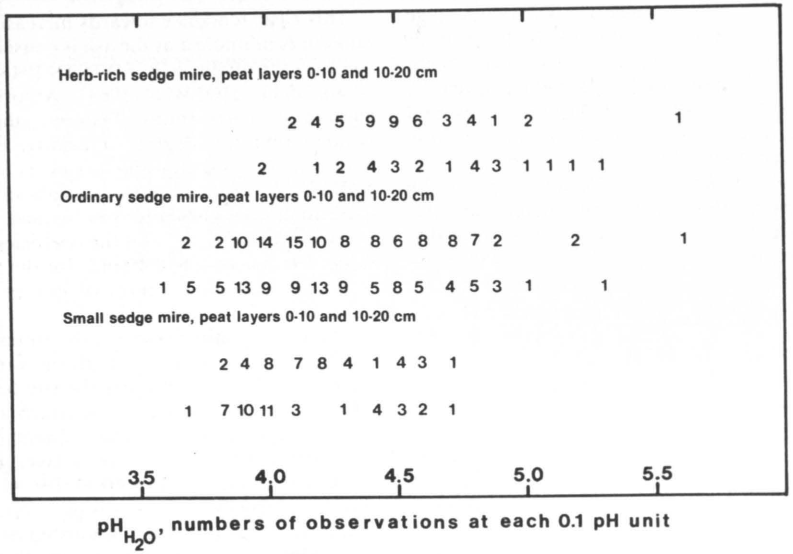

Figure 5. Active acidity (pH$_{H_2O}$) of the peat samples.

associated with the peat forming plant community, which is both conditioned by, and results in, a high hydrogen ion concentration in the soil (cf. KIVINEN 1932, 1933). When calculating by layer mean acidities for the three site types (Table 12) and comparing to those reported by VAHTERA (1955), it appears that the values for the herb-rich and ordinary sedge mires are practically identical, while the average pH for small sedge mires according to VAHTERA (1955) is surprisingly high (4.5). This result can probably be linked to the high ash contents in the peat from these poor sites as discussed in the previous chapter. Thus, one may suggest that the here observed average pH (4.07–4.18) better describes the soil acidity of the small sedge mires. HOLMEN (1964) gives for old drained pine mires even somewhat lower pH values than those reported here. This can be due to the sites in question having originally been somewhat less fertile than sedge mires. SEPPONEN et al. (1978) have investigated a number of peatlands in north Finland, both drained and undrained, giving pH values for small sedge mires and ordinary sedge mires varying from pH 3.9 to pH 4.6.

The change in pH from the small sedge mire to the herb-rich sedge mire is in the 0–10 cm layer, 0.34 pH units and in the 10–20 cm layer, 0.56 pH units. Although the difference between the most and least fertile site type is rather small, when taking into account the logarithmic nature of the pH scale, the hydrogen ion concentration is halved in the former case and reduced to a forth in the latter.

Table 12. Mean active acidity of the peat samples.

Peat layer	Active acidity, pH$_{H_2O}$		
	Herb-rich sedge mire	Ordinary sedge mire	Small sedge mire.
0–10 cm	4.52±0.04 a	4.30±0.04 b	4.18±0.04 c
10–20 cm	4.63±0.07 a	4.24±0.04 b	4.07±0.04 c

A two-way analysis of variance of the pH values shows a statistically significant variation between the site types, while the pH does not seem to be affected by the sampling depth:

	Model of variance	Between site types	Between layers	Inter-action
F-value	16.04***	18.84***	2.19	2.40
Degrees of freedom	5,351	4,351	3,351	2,351

As the pH value is already a transformed concentration value and as its distribution within the site types approaches normality (Figure 5), further transformations of the primary data was not considered necessary. Significantly different mean values clearly show that the pH increases along with increasing quality of the site. This trend is somewhat more pronouced in the lower than in the upper layer, but the difference cannot be statistically shown.

Within the recorded pH range, the hydrogen ion concentration of soil probably little affects the physiological processes of Scots pine (cf. e.g. BENZIAN 1965). Nevertheless, the pH determination is of considerable interest. What is known of soil chemically, biologically and even physically is in many respects linked to the pH and its variations (JANSSON 1978). As is apparent (Table 4), the pH is significantly correlated with all the variables included. With the exception of potassium in the 0–10 cm layer, the coefficients are throughout positive. However, the correlations are in general weak, coefficients higher than 0.40 were obtained in both layers only for the ash content and the calcium and magnesium contents and for the cation exchange capacity in the 0–10 cm layer as well as for the nitrogen content in the 10–20 cm layer. Calcium gives the highest coefficients, 0.69 and 0.59, in the lower and upper layers respectively. The connection between pH and calcium is known long since; the complicated mechanism was already described by KOTILAINEN (1927). Also HOLMEN (1964) has proved a relationship between pH and both the ash content and the nitrogen content. The site amplitude in Holmen's study is considerably broader than here and therefore general relationships of the above type appear much more clear. Overall site variables, such as pH, do not necessarily reflect the variation of single direct plant factors when the range of site types is limited as is the case in this study. The fact that the pH, in spite of weak general relationships within the site series (Table 4), is correlated with most of the soil properties appears from Tables 5–7. The correlations with the cation exchange capacity, degree of base saturation and even with the content of plant nutrients are relatively clear in a number of cases, but are strongly influenced by multicolinearity between the different variables.

The electric conductivity of the peat can be seen from the frequency diagrams in Figure 6. The values in the 0–10 cm layer range from 79 to 460 μ S· cm and in the 10–20 cm layer from 67 to 265 μ S· cm. Compared with electric conductivity indices given by PUUSTJÄRVI (1973) for horticultural peat, the figures obtained here are naturally considerably lower. SEPPONEN et al. (1978) have measured in peat for undrained or recently drained sedge mires in north Finland electric conductivities between 15 and 35 μ S. These low values are most likely due to the data being recorded from soil water from fresh peat samples, while the measurements in this study were made up from homogenized samples. HOLMEN (1964) gives specific conductivities between 37.3 and 107.4 μ ohm^{-1} cm^{-1} for peat from two drained mires, the data in this case being reduced conductivities, which involves eliminating the contribution of the hydrogen ions to the conductivity (SJÖRS 1948, MALMER 1962a, 1962b).

In spite of a considerable variation, particularly within the herb-rich sedge mires, Figure 6 indicates a tendency towards increasing conductivity from the poor to the fertile site. The mean electric conductivity has been calculated by site type for both the layers (Table 13). A two-way analysis of variance of the classified material shows significant variations between the site types as well as between the two layers:

	Model of variance	Between site types	Between layers	Inter-action
F-value	56.54***	45.33***	37.25***	16.87***
Degrees of freedom	5,351	4,351	3,351	2,351

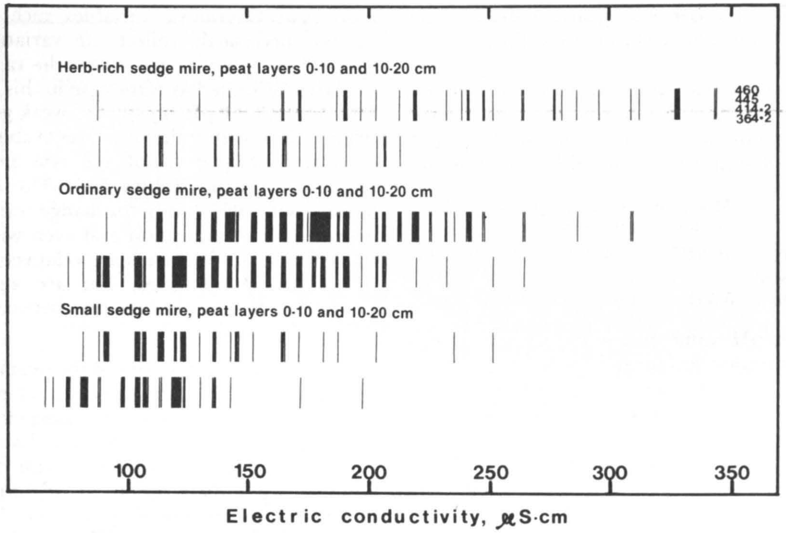

Figure 6. Electric conductivity of the peat samples.

It appears that there exists also a significant interaction between the classifying variables, which affects the interpretation of the results. If F-ratios free from this interaction are calculated, the variation between the classes turns out to be non-significant. The differences between the means are thus a result of the electric conductivity reacting differently to the classifying variables depending on which class the mean value belongs to. An effort to eliminate this interaction was made by applying different transformations. Although its F-ratio could be somewhat lowered, the effect remained.

Significance testing of the mean values shows that the total content of electrolytes in peat increases in the site series from the small sedge mires to the herb-rich sedge mires. Thus electric conductivity is doubled in the 0–10 cm layer and increased by a half in the 10–20 cm layer. However, in the lower layer the difference between the two more fertile site types cannot be statistically shown. Consequently, it seems as if the total content of electrolytes fairly well parallels the pH gradient of the site series. This tendency was also noted by HOLMEN (1964). Further, in all the site type classes the electric conductivity decreases significantly from the upper to the lower layer. The change is of the magnitude 20 per cent in peat from the two less fertile site types and as much as 40 per cent in peat from the herb-rich sedge mires.

Table 13. Mean electric conductivity of the peat samples.

Peat layer	Electric conductivity, ee/.S.cm		
	Herb-rich sedge mire	Ordinary sedge mire	Small sedge mire
0–10 cm	259±13	178±4	133±6 a b
10–20 cm	153±7 a	145±4 b	108±4

Like the soil pH, the electric conductivity is an overall site factor. By following its fluctuations it is possible, according to PUUSTJÄRVI (1973), to control the nutrient supply in horticultural peat for green-house cultivation. When examining the relationships between the electric conductivity and other site factors (Table 4), a significant correlation with most of the variables included in this study appears. The coefficients are low throughout, being higher than 0.40 only in a few cases, i.e. phosphorus, calcium and magnesium. The two latter nutrients are of particular interest. Since a relatively large proportion of the total content of these is in exchangeable form (KAILA & KIVEKÄS 1956), they can be expected to contribute to the electric conductivity of the peat. If this is determined by the ions in soil solution, then one would expect a correlation also with potassium, as this element is particularly mobile in peat soils (STARR & WESTMAN 1978, WESTMAN 1979a, MANNERKOSKI 1980). However, no correlation is found, a discrepancy which probably is due to low potassium contents. On the other hand electric conductivity is sensitive to measuring conditions (HOLMEN 1964), and thus not a particularly reliable variable for characterizing a site.

31.5 Cation exchange capacity and degree of base saturation

The effective cation exchange capacity of peat in the 0–10 cm layer falls between the extremes 14.4 and 57.6 m.e./100 g and in the 10–20 cm layer between 12.9 and 58.1 m.e./100 g (Figure 7). The means calculated by site type for both layers range between 29.6 m.e./100 g in the lower layer from the herb-rich sedge mires and 36.8 m.e./100 g in the upper layer from the small sedge mires (Table 14). SCHEFFER and SCHACHTSCHABEL (1976) give 150 m.e./100 g as an average potential cation exchange capacity for peat from raised bogs. Since the exchange capacity within the pH range 4–7 increases linearly by 50 m.e. per pH unit (HELLING et.al. 1964), the effective cation exchange capacities in sedge mire peat is of the same magnitude and possibly somewhat higher. For comparison, it can be mentioned that NÖMMIK (1974) found in forest soil raw humus, a mean effective cation exchange capacity of 26.8 m.e./100 g. Similar

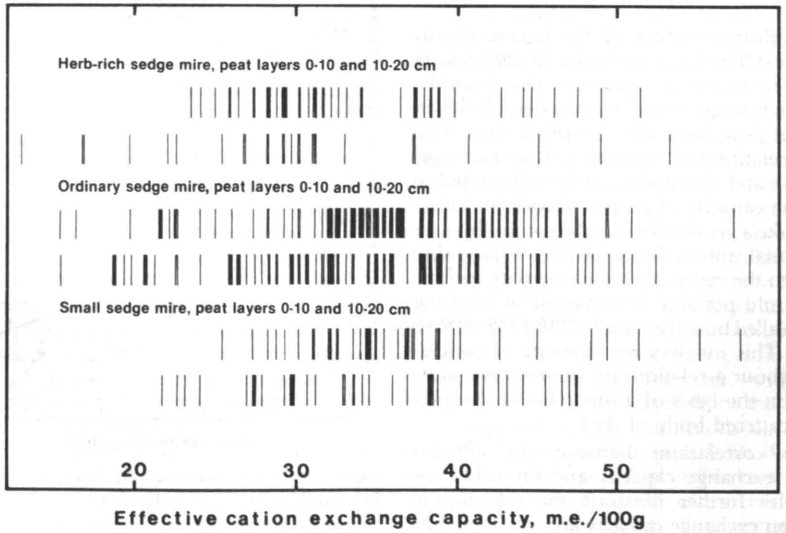

Figure 7. Effective cation exchange capacity of the peat samples.

Table 14. Mean effective cation exchange capacity of the peat samples.

Peat layer	Effective cation exchange capacity, m.e./100 g		
	Herb-rich sedge mire	Ordinary sedge mire	Small sedge mire
0–10 cm	33.9±1.03 a d	36.1±0.77 b d e	36.8±1.10 c d e
10–20 cm	29.6±2.01 a	34.4±0.89 b f	35.5±1.17 c f

data has been obtained by WESTMAN (1974) with profiles from a *Myrtillus* type pine forest.

Possibly the cation exchange capacity decreases somewhat with increasing fertility and from the upper to the lower peat layer (Table 14). The differences between the three site types and the two peat layers are, however, rather small. A two-way analysis of variance shows that there exists no statistically significant variation between the two layers, while the variation between the site types is significant.

	Model of variance	Between site types	Between layers	Interaction
F-value	3.05***	2.77*	2.16	0.45
Degrees of freedom	5,351	4,351	3,351	2,351

Significance testing of the means reveals that the differences exist in the 10–20 cm layer only. The exchange capacity in peat from the herb-rich sedge mires is considerably lower than in peat from the two other sites. This weak relationship between cation exchange capacity and site quality can be interpreted so that the capacity of peat to absorb ions does not make a growth limiting factor. In this case additional information of the relationship between the cation exchange capacity and site type could possibly be obtained by studying the so-called boundary line (WEBB 1972, SIMAN 1978). This involves the drawing of conclusions about a relationship between two variables on the basis of a line lying at the edge of a scattered body of data.

The correlations between the effective cation exchange capacity and the other site variables further illustrate the relationship between exchange capacity and site type. The coefficients in a number of cases are statistically significant (Table 4), but exceed 0.40 only for bulk density and potassium content in both the layers and for soil pH in the 0–10 cm layer. The latter relationship is easily understood considering that the dissociated carboxyl radical in organic coils is the most important component in the exchange system. The dissociation is the more complete the higher the soil pH is (cf. HELLING et al. 1964, SCHEFFER & SCHACHTSCHABEL 1976, GREENLAND & HAYES 1978). The relationship between the potassium content and the exchange capacity will be dealt with later on (ch. 31.8).

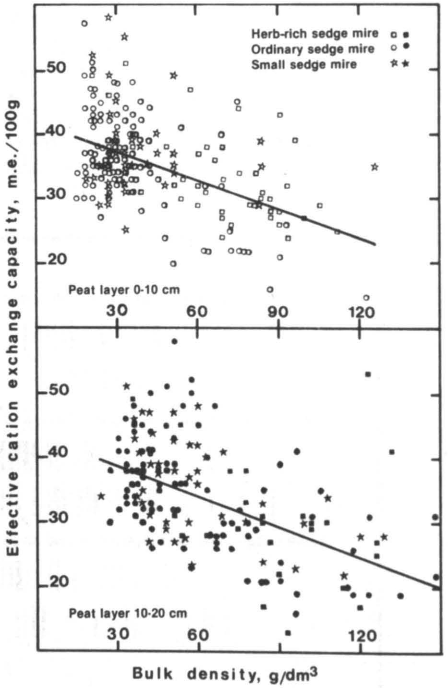

Figure 8. Scatter diagrams by layer showing the relationship between bulk density and effective cation exchange capacity. For the mathematical models see Table 15.

Table 15. The regression models for the relationship between bulk density (X) and effective cation exchange capacity (Y).

Peat layer	Regression				Analysis of variance	
	Constant	Regr. coeff.	T-value	R^2	d.f.	F-value
0–10 cm	42.201	–0.1448	7.79***	0.242	1,190	60.69***
10–20 cm	43.690	–0.1497	7.69***	0.266	1,163	59.15***

The negative relationship between effective cation exchange capacity and bulk density is of interest. The relationship is illustrated by linear regressions as presented in Figure 8 and Table 15. An explanation must most likely be sought in the relative proportions of the humus fractions in the peat. GREENLAND and HAYES (1968) generally state that, the content of oxygen in humus material decreases along with increasing degree of decomposition. This involves reducing acid character of the organic matter and thus both the degeree of acidity and the cation exchange capacity decrease. The same general causality is also given by SCHEFFER and SCHACHTSCHABEL (1976) with reference to OGNER and SCHNITZER, who have found that in particular fulvic acids contain functional organic groups rich in oxygen. Characteristic of this humus fraction is that it is an initial product in the decomposition process and is formed especially when the biological activity in the soil is low. On this basis the negative correlation between exchange capacity and bulk density could be explained by the increasing degree of decomposition with increasing bulk density (cf. e.g. PÄIVÄNEN 1973).

The question then remains why there does not exist a comparable connection between exchange capacity and the volume weight of organic matter, which is supposed to be a measure of the degree of decomposition. A definitive answer cannot be given on the vasis of this material, but in general, the relationship between the bulk density and the volume weight of organic matter is unclear (Tables 4–7). The volume weight of organic matter is an artificial variable and as such not a particularly good site factor (see ch. 31.2.).

The relationship between the cation exchange capacity and the bulk density is relevant when examining as above, the exchange capacity of peat by site type. When using the bulk density as a co-variate in the previous model of variance, there exist no differences even between the site types:

	Model of co-variance	Between site types	Between layers	Interaction
F-value	21.89***	1.21	1.36	0.31
Degrees of freedom	6,349	4,349	3,349	2,349

The significantly lower exchange capacity in peat from the 0–10 cm layer from the herb-rich sedge mires (Table 14) can consequently be explained by the high bulk density of peat from this site type (Table 8).

In this study the effective cation exchange capacity is calculated as the sum of exchangeable calcium, magnesium, aluminium and hydrogen. The percentage ratio of the two former elements to the total exchange capacity measures the degree of base saturation. The content of exchangeable bases in the 0–10 cm layer ranges from 24 to 79 per cent and in the 10–20 cm layer from 22 to 86 per cent (Figure 9). Base saturation degrees as high as 70–80 per cent can possibly be considered erroneous. However, with the exception of the lower layer from the herb-rich sedge mires, base saturations up to 80 per cent are frequent in peat from the two more fertile site types. A plausible reason for this can be found in the cation exchange capacity determined being effective and also in the calcium and magnesium balance of the

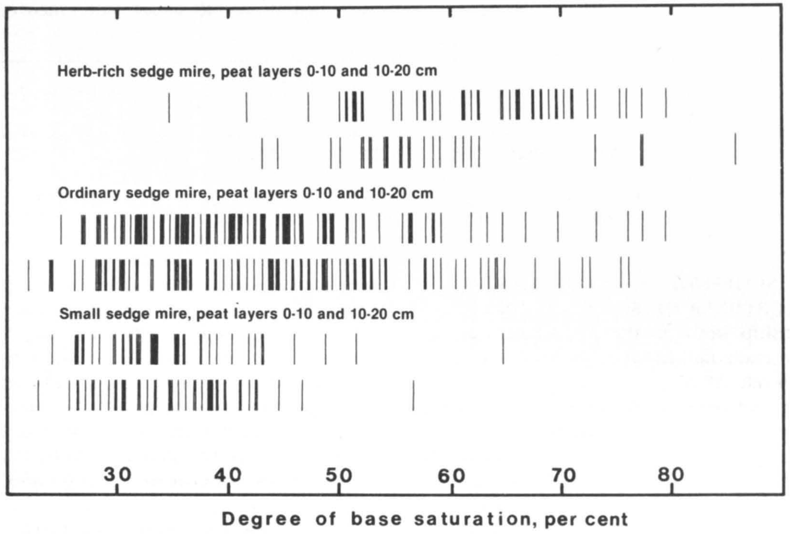

Figure 9. Degree of base saturation in the peat samples.

peat from these sites (see ch. 31.9–10). A considerable proportion of the total content of these two elements in the peat is in an exchangeable from (STARR & WESTMAN 1978). Thus, the acid cations do not necessarily dominate in the exchange complex as is the case when potential exchange capacity is determined (cf. NÖMMIK 1974). The high degrees of base saturation are consistantly associated with high contents of calcium in peat.

Average degrees of base saturation are given in Table 16. The values in the upper layer vary between 35.2 and 61.9 per cent and in the lower layer between 35.0 and 50.6 per cent. A rather clear tendency towards an increasing proportion of basic cations in the exchange system with increasing fertility can be seen. A two-way analysis of variance gives a statistically significant variation between the site types, while the two layers do not differ from each other:

	Model of variance	Between site types	Between layers	Interaction
F-value	44.84***	55.56***	0.83	1.24
Degrees of freedom	5,351	4,351	3,351	2,351

Testing of the differences between the means shows that the site types in this respect differ significantly from each other. Consequently, the degree of base saturation follows the site quality gradient characterizing the site series studied. Set against the content of calcium and magnesium in peat (ch. 31.9–10) and the pH gradient shown in the previous this relationship is logical.

Table 16. Mean degree of base saturation in the peat samples.

Peat layer	Base saturation, per cent		
	Herb-rich sedge mire	Ordinary sedge mire	Small sedge mire
0–10 cm	61.9±1.43 a	43.0±1.17 b	35.2±1.21 c
10–20 cm	50.6±8.06 a	44.4±1.32 b	35.0±1.00 c

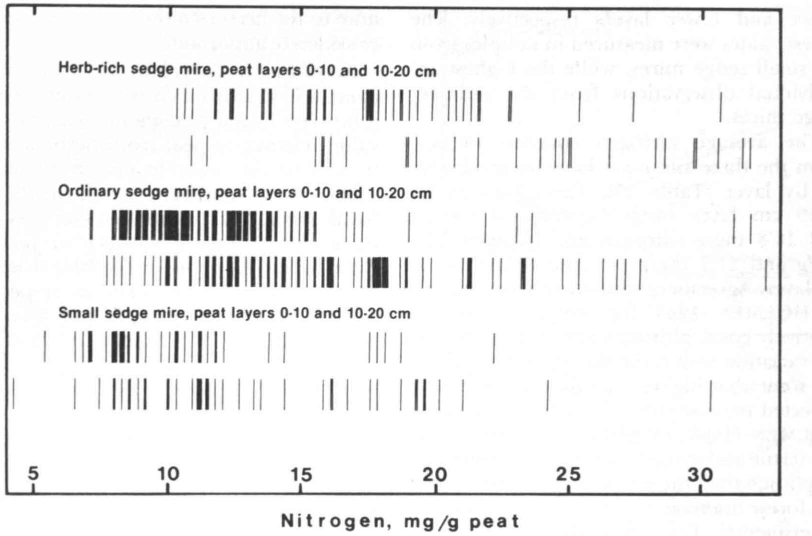

Figure 10. Total content of nitrogen in the peat samples.

The method used to determine the effective cation exchange capacity of peat is relatively simple. NÖMMIK (1974) emphasizes that the contribution of potassium and sodium ions to the cation exchange capacity of forest soil raw humus is of the magnitude 9–10 per cent. On the basis of STARR's and WESTMAN's (1978) and WESTMAN's (1979a) studies, the exchangeable potassium in peat from the sites examined here, in the 10–20 cm layer vary between 0.7 and 1.7 m.e./100 g. The effective cation exchange capacity in the lower layer has, therefore, been underestimated by between 2 and 4.5 per cent. In the upper layer the error is probably somewhat more pronounced, since the potassium contents there are considerably higher (see ch. 31.8). The error is, however, clearly smaller than that given by NÖMMIK (1974). The difference to be expected is natural since, on one hand, potassium content of peat is limited and, on the other hand, the raw humus is influenced by the underlying mineral soil.

31.6 Total content of nitrogen

The total content of nitrogen in peat from the site types studied can be seen in the frequency diagrams in Figure 10. The data vary from 5.5 mg/g to 31.8 mg/g nitrogen and from 4.5 mg/g to 32.5 mg/g nitrogen in the

Table 17. Mean total content of nitrogen in the peat samples.

Peat layer	Total content of nitrogen, mg/g		
	Herb-rich sedge mire	Ordinary sedge mire	Small sedge mire
0–10 cm	$16.8^{+0.63}_{-0.61}$ a	11.8±0.32 b	$10.0^{+0.49}_{-0.47}$
10–20 cm	$21.7^{+1.32}_{-1.24}$	$15.4^{+0.49}_{-0.47}$ a	$12.5^{+0.76}_{-0.72}$ b

upper and lower layers respectively. The lowest values were measured in samples from the small sedge mires, while the highest are individual observations from the ordinary sedge mires.

The average nitrogen contents in peat from the three site types have been calculated by layer (Table 17). The values in the 0–10 cm layer range between 10.0 mg/g and 16.8 mg/g nitrogen and between 12.5 mg/g and 21.7 mg/g in the 10–20 cm layer. Agreement with the results obtained by HOLMEN (1964) for comparable sites is relatively good, although both the means and the variation within the site types given above are somewhat higher. The differences can be expected to arise from the sites examined by HOLMEN (1964) originally being somewhat less fertile and spread over a more limited site amplitude than the sedge mires. Possibly also the forest drainage carried out on Holmen's experimental field has affected the soil properties. VALK (1973) and DAMMAN (1978) have found similar nitrogen contents in peat from ombrogenous mires. HEIKURAINEN (1953) gives total nitrogen contents from 12.0 to 26.5 mg/g nitrogen in peat from eutrophic pine mires in north Finland.

A tendency towards increasing nitrogen content in peat from the upper to the lower layer and in the site series from the small sedge mires to the herb-rich sedge mires can be seen (Figure 10 and Table 17). An analysis of variance after logarithmic transformation of the nitrogen contents shows that the variation between the site types as well as between the two layers is statistically significant:

	Model of variance	Between site types	Between layers	Interaction
F-value	33.47***	30.63***	20.28***	0.12
Degrees of freedom	5,350	4,350	3,350	2,350

Significance testing of the means (Table 17) reveals that the assumption of a relationship between nitrogen content and site type as well as peat layer is true. The increase in nitrogen parallels the productivity (quality gradient) of the sites, being 10–20 per cent from the small sedge mire to the ordinary sedge mire and as much as 40 per cent from the ordinary sedge mire to the herb-rich sites. The trend must be considered important.

According to VAHTERA (1955) the nitrogen content in peat from corresponding site types is between 19 and 20 mg/g nitrogen, the higher value relating to peat from herb-rich sedge mires and the lower to peat from ordinary sedge mires. HOLMEN (1964), on the other hand, gives average nitrogen contents of 7.5 mg/g and 17.0 mg/g nitrogen in peat from *Pinus-Ledum-Pleurozium* and *Pinus-Vaccinium-Myrtillus-Pleurozium* associations respectively. The values are somewhat lower than those found here, but clearly indicate, despite the small number of observations, a positive relationship between nitrogen and site quality.

The connection between depth of sampling and total content of nitrogen is well known (ISOTALO 1951, HOLMEN 1964, PAKARINEN & TOLONEN 1977, DAMMAN 1978). Since this study is limited to a 20 cm deep profile divided into two layers only the increase in nitrogen content is consistent, being 25–35 per cent (Table 17). This change can in all probability be attributed to increasing humification which occurs along with greater depth (cf. Tables 8, 10). According to ISOTALO (1951) the nitrogen content of *Sphagnum* peat increases from 0.77 to 1.72 per cent when the degree of humification rises from von POST (1922) scale H1 to H8. The corresponding values for *Carex* peat are 1.78 and 2.43 per cent nitrogen for H5 and H9 respectively. The change, which on average is 1–1.5 mg nitrogen per von POST (1922) scale degree of humification, is due partly to a relative increase in resistant organic compounds such as lignin and proteins, and partly to the increase in bulk density taking place in the decomposition process.

The correlation between the content of nitrogen in peat and both the bulk density and the volume weight of organic matter is statistically significant showing relatively high coefficients (Table 4). As there is also within the individual site types clear correlations (Tables 5–7), it might be worth clarifying how the nitrogen content is affected by the bulk density. Because of theoretical considerations the volume weight of organic matter has been left out of this examination (see ch. 31.2).

When using the bulk density as a co-variate in the model of variance composed above, one finds that the F-value for the whole model increases and that its degree of explanation rises to over 50 per cent:

	Model of co-variance	Between site types	Between layers	Interaction
F-value	58.35***	13.93***	4.65***	0.78
Degrees of freedom	6,349	4,349	3,349	2,349

The variations between the site types as well as between the peat layers are still significant, but the respective F-values are considerably lower. The remarkable increase in the nitrogen content from the ordinary sedge mires to the herb-rich sites is thus a result of the high bulk density of peat from the latter site type (Tables 8, 17). From layerwise calculated regressions for the relationship between bulk density and nitrogen content (Figure 11, Table 18), it can be estimated that the high bulk density has increased the nitrogen content in peat from the herb-rich sedge mires by on average 2.5 mg/g and 3.3 mg/g nitrogen in the 0–10 cm and 10–20 cm layers respectively. When correcting, on the basis of the co-variate, the nitrogen content of the herb-rich sedge mires, the change from the ordinary to the herb-rich sites is approximately 20 per cent.

The figures obtained by significance testing of the average nitrogen contents are not affected by inserting the bulk density as a corrective term. The relationships between the nitrogen content of peat and the quality gradient of the site series is consequently well confirmed.

It may be added that the nitrogen contents were corrected on the basis of the layerwise calculated regressions (Table 18), because no difference between coefficients taken out separately for each site type could be shown:

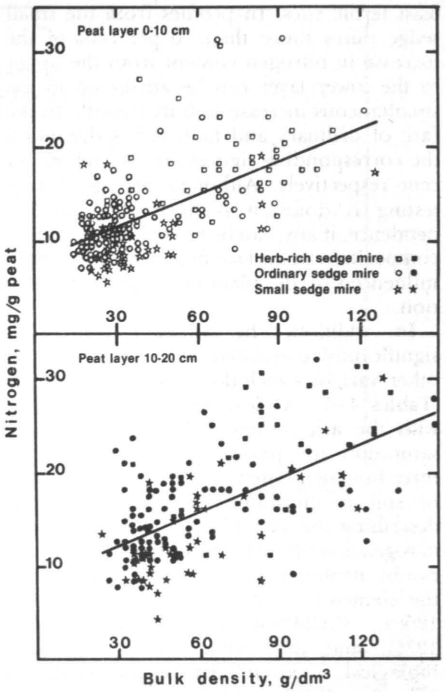

Figure 11. Scatter diagrams by layer showing the relationship between bulk density and total content of nitrogen in peat. For the mathematical models see Table 18.

	Layer 10–20 cm	Layer 0–10 cm
F-value	1.35	1.87
Degrees of freedom	2,185	2,159

When splitting up the relationship between nitrogen content, bulk density and depth in profile (Table 18), bulk density affects the nitrogen content the most in peat from the

Table 18. The regression models for the relationship between bulk density (X) and total content of nitrogen (Y).

Peat layer	Regression				Analysis of variance	
	Constant	Regr. coeff.	T-value	R²	d.f.	F-value
0–10 cm	8.051	0.1138	10.64***	0.374	1,190	113.34***
10–20 cm	8.676	0.1201	9.60***	0.361	1,163	92.25***
0–20 cm	8.046	0.1227	15.86***	0.415	1,355	251.60***

least fertile sites. In profiles from the small sedge mires more than 70 per cent of the increase in nitrogen content from the upper to the lower layer can be attributed to the simultaneous increase in bulk density. In the case of ordinary and herb-rich sedge mires the corresponding figures are 64 and 60 per cent respectively. Although no significance testing is done, it is likely that site dependence, if any, can be related to the organic composition of surface peat, which in turn is influenced by the plant community in question.

In addition, the nitrogen content is significantly correlated with a number of other variables included in the investigation (Tables 4—7). A clear relationship is found with the ash content, pH, degree of base saturation and phosphorus content. In the three first mentioned cases the nitrogen status of soil is illustrated by overall variables describing the site. The correlation between nitrogen and phosphorus (Figure 12, Table 19) can be attributed to the fact that in peat both the elements are organically bound (KAILA 1956a, SCHEFFER & SCHACHTSCHABEL 1976), and thus subjected to the same biological immobilization-mineralization processes. On the other hand, it is also clear that the relationship is affected by multicolinearity between site quality and nitrogen and phosphorus contents (c.f. Tables 17 and 20).

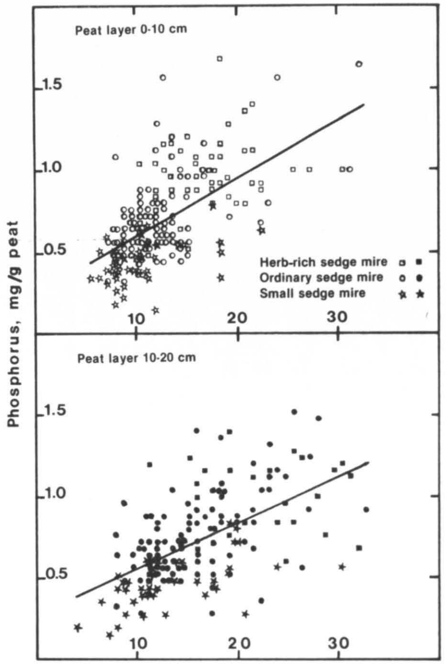

Figure 12. Scatter diagrams by layer showing the ralationship between total content of nitrogen and phosphorus in peat. For the mathematical models see Table 19.

The content of total nitrogen (mg N/g) follows the established quality gradient of the site series investigated. In order to evaluate the timber production potential of a site it is important to know also the absolute amounts of nutrients in the soil. Using bulk density of peat, the nitrogen contents have been transformed to absolute amounts expressed in kilogram per hectare by layer (Figure 28). A two-way analysis of variance after logarithmic transformation of the absolute amounts gives similar results as for the concentration contents already discussed. Significant variations between the layers as well as between the site types are shown:

	Model of variance	Between site types	Between layers	Interaction
F-value	43.30***	32.63***	36.62***	0.70
Degrees of freedom	5,350	4,350	3,350	2,350

Table 19. The regression models for the relationship between total contents of nitrogen (X) and phosphorus (Y).

Peat layer	Regression				Analysis of variance	
	Constant	Regr.coeff.	T-value	R^2	d.f.	F-value
0—10 cm	0.2491	0.0361	10.62***	0.373	1,190	112.85***
10—20 cm	0.2804	0.0282	8.92***	0.328	1,163	79.62***

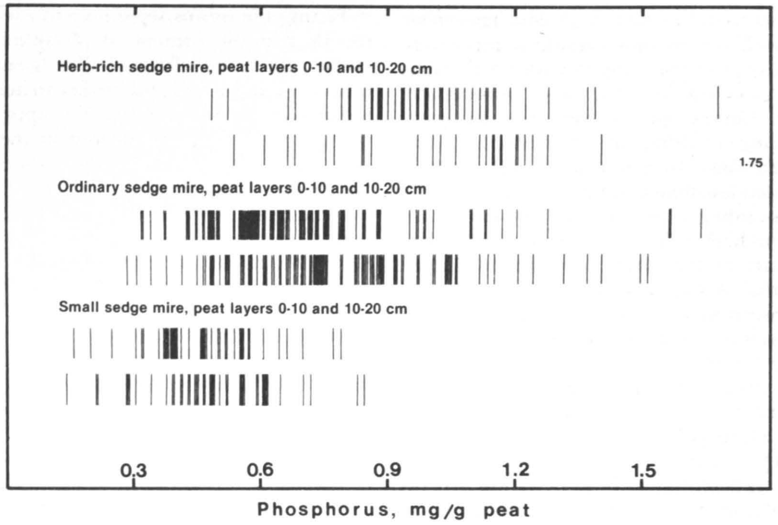

Figure 13. Total content of phosphorus in the peat samples.

The histogram in Figure 28 indicates, however, that the differences between the individual site types are not as clear as when the nitrogen status was expressed on the bases of concentration values. Significance testing of the means show that in both the layers the difference between the two less fertile site types have been levelled (Table 29). In peat from the herb-rich sedge mires the amount of nitrogen is as much as 150—170 per cent higher than in peat from the two other site types. These trends are results of the bulk density in peat from the most fertile site type being considerably higher than in peat from the two other types. The primary effect of bulk density on the nitrogen content (cf. above) is intensified by the transformation into absolute amounts.

31.7 Total content of phosphorus

The total content of phosphorus in the peat samples examined can be seen from the frequency diagrams in Figure 13. In the 0—10 cm layer the contents vary between 0.17 mg/g and 1.65 mg/g phosphorus and in the 10—20 cm layer from 0.15 mg/g to 1.75 mg/g phosphorus. The lowest data is recorded in samples from the small sedge mires and the highest are individual observations from the two more fertile site types. The average phosphorus contents in the classes are given in Table 20. In the upper layer the mean values range from 0.45 mg/g to 0.96 mg/g and in the lower layer from 0.46 mg/g to 1.00 mg/g phosphorus.

When comparing the data obtained here

Table 20. Mean total content of phosphorus in the peat samples.

Peat layer	Total content of phosphorus, mg/g		
	Herb-rich sedge mire	Ordinary sedge mire	Small sedge mire
0—10 cm	$0.96\ ^{+0.033}_{-0.031}\ \underline{a}$	$0.67\ ^{+0.022}_{-0.021}\ \underline{b}$	$0.45\ ^{+0.023}_{-0.021}\ \underline{c}$
10—20 cm	$1.00\ ^{+0.055}_{-0.052}\ a$	$0.74\ ^{+0.026}_{-0.025}\ b$	$0.46\ ^{+0.026}_{-0.024}\ c$

with that found by KAILA (1956b), agreement both with means and variations for corresponding peat types is satisfactory. VAHTERA (1955) gives, on the other hand, considerably higher figures for phosphorus in peat. According to him, of the *Sphagnum* peat analysed only 16 per cent of the samples contained less than 0.9 mg/g phosphorus, the corresponding proportion for the *Carex* peat being no higher than 10 per cent. A considerable part of the *Carex* peat contained even more than 3.0 mg/g phosphorus, which must be considered as particularly high values. In this investigation the phosphorus content is in all the samples from the small sedge mires lower than 0.9 mg/g. The corresponding proportions in peat from the ordinary and herb-rich sedge mires are 75–85 per cent and 65–70 per cent respectively. The peat type has not been determined, but one can in general assume that the proportion of the *Sphagnum* factor decreases along with increasing fertility in the site series in question.

KAILA (1956b) supposes that VAHTERA's (1955) data is impaired by some analytical error. This criticism is supported by comparison with results obtained by HOLMEN (1964), VALK (1973), PAKARINEN and TOLONEN (1977) and DAMMAN (1978). In alla these cases the content of phosphorus in peat is of the same magnitude as recorded here, or somewhat lower, due to the fact that most of the studies referred to regard peat from ombrogeneous peatlands.

In examining the frequency diagrams in Figure 13 one will find in the site series from the least to the most fertile site type a clear trend towards increasing content of phosphorus. Further, a slight increase in content of phosphorus from the upper to the lower peat layer can possibly be seen. After logarithmic transformation of the phosphorus contents a two-way analysis of variance shows a significant variation between the three site types. The variation between the two layers is non-significant:

	Model of variance	Between site types	Between layers	Interaction
F-value	47.42***	59.17***	1.60	0.44
Degrees of freedom	5,350	4,350	3,350	2,350

Testing the means separately in each layer reveals that the content of phosphorus increases significantly from small sedge mires to ordinary sedge mires and further to herb-rich sedge mires. The change in the upper layer being 50 and 35 per cent and in the lower layer 60 and 35 per cent respectively. HOLMEN (1964) gives for comparable sites 0.51 mg/g and 0.62 mg/g phosphorus; values which agree with the tendency found in this study. The increase in the phosphorus content of peat which doubles from the least to the most fertile site in the site series thus seems to be valid. On the other hand, surface peat from eutrophic mires, in the trophy series next to the sites studied here, according to HEIKURAINEN (1953) contains on average only 0.45 mg/g phosphorus.

If phosphorus in peat is expressed in absolute amounts in both the layers the same trend as for the concentration values can be seen (Figure 28). The difference between the least and the most fertile sites has even increased; the absolute amount of phosphorus is more than trebled. A two-way analysis of variance after logarithmic transformation of the data shows that the variation between the site types is statistically significant:

	Model of variance	Between site types	Between layers	Interaction
F-value	45.32***	45.39***	22.45***	1.18
Degrees of freedom	5,350	4,350	3,350	2,350

Testing of the paired means (Table 29) proves that the difference between the individual site types is in all the cases significant. Phosphorus in peat soils is a critical growth factor (cf. HUIKARI & PAAVILAINEN 1972, SEPPÄLÄ & WESTMAN 1976), unlike in mineral soils. Therefore the relationship between site type and the phosphorus economy can be considered important and possibly provides a suitable means for evaluating conditions for timber production.

It is generally considered that the content of phosphorus in peat decreases with increasing sampling depth in the profile (e.g. WARÉN 1921, HOLMEN 1964, PAKARINEN & TOLONEN 1977, DAMMAN 1978). The tendency towards a positive relationship found here is, therefore, somewhat unexpected. The average contents in Table 20 indicate increases up to 10 per cent, although the trend is not statistically significant. When transforming the phosphorus contents into absolute amounts this increase from the upper to the lower layer is clear (Figure 28). Statistical testing (see above, Table 29) also verifies this tendency in profiles from all the site types. The change, which is between 45 and 85 per cent, is understandable as the bulk density simultaneously increases by on average 40 to 70 per cent (Table 8).

KAILA (1956b) points out that the phosphorus content in peat from sites low in fertility possibly decreases along with increasing depth while the opposite takes place in profiles from more fertile sites. No clear correlation could, however, be shown. On the other hand, the content of mineral phosphorus was clearly negatively correlated to sampling depth. In addition also the extractability of this fraction was negatively correlated to sampling depth. Consequently, the determination of mineral phosphorus can result in decreasing contents along with increasing sampling depth, although total phosphorus does not necessarily decrease. This could possibly be the case with HOLMEN's (1964) data, which vas obtained by extraction with hydrochloric acid. In PAKARINEN's and TOLONEN's (1977) as well as in DAMMAN's (1978) studies, wet combustions were applied and, therefore, the values are certainly total phosphorus contents. Further, it should be taken into account that the peat profiles in the studies mentioned are deeper than 20 cm and have been split up in thinner sample layers, thus giving greater detail. KAILA (1956b) in her study has compared layers the thickness of which varies between 10 and 40 cm.

The reasons for the relationship between phosphorus and sample depth in this study differing from a generally accepted model cannot be established. Possibly the behavior of phosphorus varies with site type (cf. KAILA 1956b). The data referred to are largely concerned with more or less pronounced ombrogeneous raised bogs where the capacity of living plants to concentrate in plant tissue the scanty nutrient reserves with all probability is high (cf. VAHTERA 1955, PUUSTJÄRVI 1968). The sedge mires, on the contrary, are peatlands the mire plane of which is on approximately the same level as the surrounding mineral soils and are thus more or less minerogeneous. As phosphorus, like nitrogen, in peat is fixed in organic forms, it is possible that the increase in bulk density from the upper to the lower layer affects also the phosphorus balance. The correlation between phosphorus and nitrogen (Figure 12, Table 19) as well as that between phosphorus and bulk density (Tables 4–7) imply such an interpretation. Phosphorus content corrected with bulk density would consequently, with all probability, be negatively related to sample depth in the profile.

31.8 Total content of potassium

The potassium content in peat varies within wide ranges, in the 0–10 cm layer between 0.13 mg/g and 4.18 mg/g and in the 10–20 cm layer between 0.01 mg/g and 2.01 mg/g potassium (Figure 14). The highest contents are obtained with samples from the ordinary sedge mires and the lowest with samples from the small sedge mires. Variation is considerable also within the individual site types, the coefficients of variation ranging from 42 to 82 per cent. This heterogeneity of potassium in peat has previoisly been noted by VAHTERA (1955), and can possibly be attributed to the weak fixation of the potassium ion in the cation exchange complex (KAILA & KIVEKÄS 1956, SCHEFFER & SCHACHTSCHABEL 1976, STARR & WESTMAN 1978). As a consequence the potassium ion is easily influenced by soil water movements.

The contents in Figure 14 are higher throughout than the ones given by VAHTERA (1955) for *Sphagnum* and *Carex* peat from the 10–20 cm layer. In the former case, the potassium content in 57 per cent of the analysed samples was lower than 0.25 mg/g, the corresponding proportion in the latter case being as high as 83 per cent. HOLMEN (1964), too, presents potassium contents lower than the ones here. Since both the studies concern drained peatlands one can assume that the regulation of soil water has influenced the potassium balance of the soil. In particular after drainage, the accelerated stand growth may have resulted in an

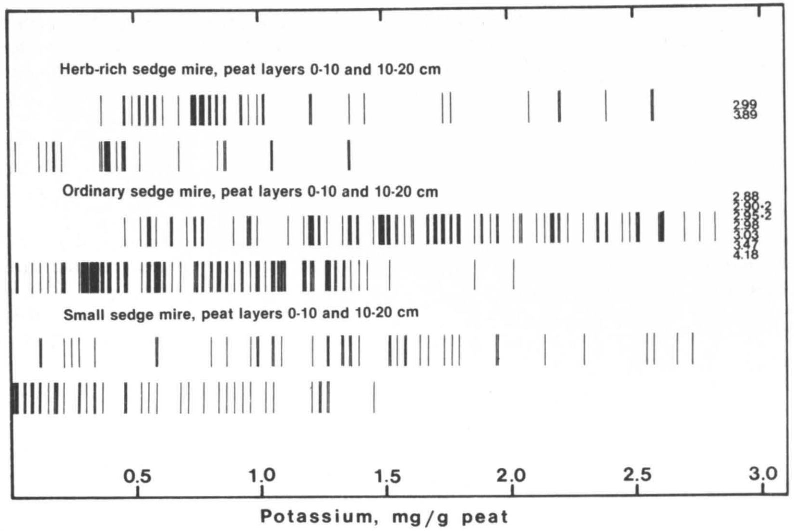

Figure 14. Total content of potassium in the peat samples.

increased biological fixation of potassium. A loss of potassium in drainage waters may also take place (cf. KENTTÄMIES 1980).

In Table 21 has been calculated for both layers the mean potassium contents of the site types. In the 0–10 cm layer the data vary between 1.05 and 1.69 mg/g potassium and in the 10–20 cm layer between 0.42 and 0.69 mg/g potassium. The highest contents is found in peat from the ordinary sedge mires, while the potassium content in peat from the least and most fertile site types is of the same magnitude.

A two-way analysis of variance after square root transformation of the potassium data shows a significant variation between the two peat layers, and also between the three site types:

	Model of variance	Between site types	Between layers	Inter-action
F-value	47.46***	11.26***	67.52***	1.45
Degrees of freedom	5,350	4,350	3,350	2,350

Testing paired mean values by a Student-Newman-Keul's test show a significant decrease in the potassium content of peat by 55–70 per cent from the upper to the lower layer. This trend towards rapid decrease in potassium content in the topmost peat layer has been established in several studies earlier (e.g. VAHTERA 1955, KAILA & KIVEKÄS 1956, HOLMEN 1964, MANNERKOSKI 1973, PAKARINEN & TOLONEN 1977, DAMMAN 1978, PAKARINEN 1978) and is explained as follows. The surface vegetation can effectively take up the potassium ions bound weakly in peat, and thus concentrate the element to the upper soil layer, where a quick turnover takes place (cf. PUUSTJÄRVI 1968). Redistribution within the constantly growing *Sphagnum* mosses may be of certain importance. Leaching from the living vegetation, in particular the tree stand, also affects the potassium status of soil (cf. PÄIVÄNEN 1974, LEHTONEN et al. 1976).

Closer examination of the variation between site type and potassium content (Table 21) shows that the ordinary sedge mires significantly differ from the two other site types. The content in peat from the least and most fertile sites is 30–40 per cent lower. The fact that the relationship between the potassium content of peat and both the peat type and the peat forming vegetation is weak has previously been stated in a number of studies. WARÉN (1924) reports that no regular connection exists between potassium and the botanical composition of the ground vegetation. BRENNER (1930) is of the opinion that the potassium content is no higher in peat from eutrophic fens than in peat under other vegetation types. Fom HEIKURAINEN's (1953) work on eutrophic pine mires in North Finland can be derived an average potassium content of 0.28 mg/g.

Table 21. Mean total content of potassium in the peat samples.

Peat layer	Total content of potassium, mg/g		
	Herb-rich sedge mire	Ordinary sedge mire	Small sedge mire
0–10 cm	$1.05\,^{+0.098}_{-0.094}$ <u>a</u>	$1.69\,^{+0.074}_{-0.072}$	$1.22\,^{+0.118}_{-0.113}$ ^{a}
10–20 cm	$0.48\,^{+0.069}_{-0.064}$ <u>b</u>	$0.69\,^{+0.045}_{-0.043}$	$0.42\,^{+0.067}_{-0.062}$ ^{b}

The unfavourable potassium status of the most fertile site type compared with the ordinary sedge mires must be seen against this background. The reason can lie in a relatively mobile soil water in the most fertile sites resulting in leaching losses of potassium. The mobility of the potassium ion is probably further affected by a more heterogeneous plant cover on these sites than on the two other site types. That the coverage of the bottom vegetation layer is not always complete can be derived from Table 1. One can also assume that litter from a fertile vegetation is less resistant to decay than litter from white mosses and sedges frequent on the two poorer sites. The relationships found by PUUSTJÄRVI (1956) between the cation exchange capacity and peat type as well as the peat forming plant community further confirm this explanation. Antagonism between cations in the exchange complex may also have affected the potassium status of peat (cf. ch. 31.5, 31.9–10). The role of the tree stand must also be taken into account. The more fertile the site is the faster is the stand development after drainage, which results in an ever increased biological fixation of potassium (cf. HOLMEN 1964).

VAHTERA (1955) states that with a potassium content in peat of the magnitude 0.25 mg/g, the sedge mires are rather unfavourable sites. A difference of 0.03 mg/g between the most and the least fertile sites is most likely not statistically significant. The average contents in this study (Table 21) give, however, a more favourable picture of the site series. When calculating on the basis of the bulk density the absolute amount of potassium (Figure 28), also the herb-rich sites adopt a logical position in the site quality gradient of the site series.

A two-way analysis of variance:

	Model of variance	Between site types	Between layers	Inter-action
F-values	14.81****	6.60***	14.42***	0.80
Degrees of freedom	5,351	4,351	3,351	2,351

and significance testing of the means (Table 29) show that, with the exception of the herb-rich sedge mires in the 10–20 cm layer, the mean absolute amounts differ significantly. In the upper layer the amount of potassium increases from the small sedge mires to the ordinary sedge mires and further to the herb-rich sedge mires in both cases by some 20 per cent. In the lower layer a corresponding increase of 50 and 65 per cent, respectively, takes place. The relationship between potassium in peat and site type is thus clear when using absolute amounts. It is also of considerable importance that the absolute amount of potassium does not decrease from the upper to the lower layer as much as the concentration data does. The absolute amounts decrease by only between 20 and 40 per cent as compared to the decrease in concentration values of between 55 and 70 per cent from the 0–10 cm layer to the 10–20 cm layer. Consequently, when evaluating the conditions for timber production on the basis of peat fertility, bulk density must be considered an important site factor.

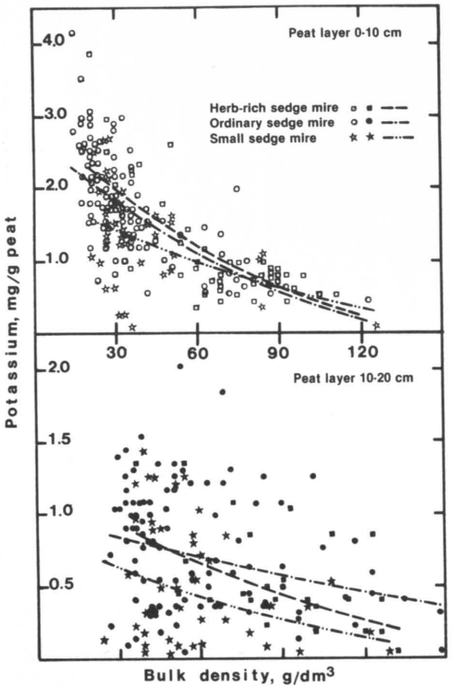

Figure 15. Scatter diagrams by layer showing the ralationship between bulk density and total content of potassium in peat. For the mathematical models see Table 22.

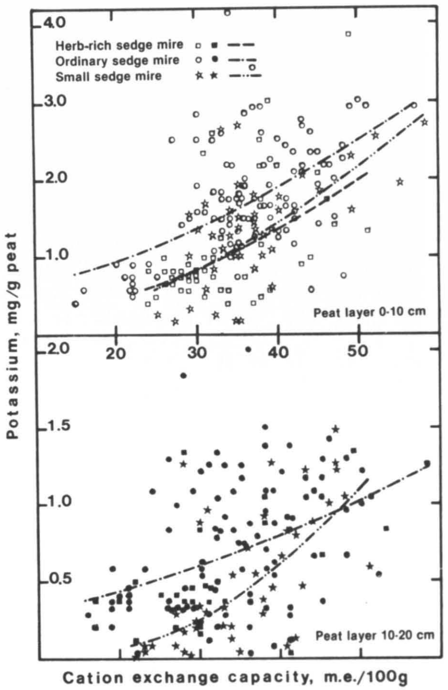

Figure 16. Scatter diagrams by layer showing the relationship between effective cation exchange capacity and total content of potassium in peat. For the mathematical models see Table 22.

The corrective effect of the bulk density of peat when transforming the potassium contents into absolute amounts is clear. It is therefore interesting to note the negative correlations in both the upper and the lower layers between bulk density and potassium content. (Table 4, Figure 15). Since the potassium ion in organic soils is mainly absorbed in the cation exchange complex, it is likely that this negative correlation is indirect. It is evident that a positive correlation prevails between potassium content and effective cation exchange capacity (Table 4, Figure 16), while there is a negative correlation between cation exchange capacity and bulk density (Table 4, Figure 8). The negative relationship between potassium content and bulk density would thus be explained by multicolinearity between these three variables. A closer examination shows, however, that this hypothesis does not satisfactorily explain the relationship between potassium content and bulk density. In the 0–10 cm layer the bulk density of peat explains as much as 49 per cent of the variations of the square root transformed potassium data while the degree of explanation by the effective cation exchange capacity is 28 per cent. In the lower layer the degrees of explanation are only 12 and 18 per cent respectively. Consequently, it appears as if the bulk density does immediately affect the potassium status of peat. This assumption is confirmed when examining, by site type, the partial correlations between the transformed potassium contents ($\sqrt{k}$) and the bulk density (B.D.) and the effective cation exchange capacity (C.E.C.):

partial correlations, $^{r}\sqrt{K}$

	1,1	2,1	3,1	1,2	2,2	3,2 [1]
B.D.	0.34*	0.49***	0.54***	0.57***	0.11	0.02
C.E.C.	0.17	0.23*	0.54***	0.16	0.28**	0.59***

In most cases after elimination of the effective cation exchange capacity the correlation between bulk density and potassium content is statistically significant and fairly strong. Only in the ordinary and small sedge mires in the 10–20 cm layer does the cation exchange capacity give stronger correlation with the potassium content than the bulk density.

The explanation for the relationship between cation exchange capacity and potassium content, which are causally related, being overshadowed by a relationship with bulk density, can partly be found in the site-dependent variation of the variables. According to Table 8 bulk density in peat from the herb-rich sedge mires is in both layers significantly higher than that in peat from the two other site types; the difference is of the magnitude 60–80 per cent. Since also the potassium content in peat from the first mentioned site type is low (Table 21), this affects the layerwise calculated correlation. The fact remains, however, that there is in the individual site types a somewhat stronger relationship between potassium content and bulk density than between potassium content and cation exchange capacity. Equations for the regressions calculated separately for each layer can be seen in Table 22.

Why the bulk density to such a degree affects the potassium content of peat, as a concentration value (mg/g), cannot be answered on the basis of this material. It deserves pointing out that when weighing a peat sample for analysis, a considerably larger volume of peat is obtained from samples at low bulk density than from samples at a higher bulk density. If the specific charge density of organic matter (m.e./cm^2) is constant, like that of clay minerals (SCHEFFER & SCHACHTSCHABEL 1976), in the former case a higher exchange capacity will be obtained. Although this relates to the cation exchange capacity of the peat, it does not necessarily imply that the capacity measured

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[1] First number refers to site type. Herb-rich sedge mire = 1, ordinary sedge mire = 2, small sedge mire = 3. Second number refers to peat layer. 0–10 cm = 1, 10–10 cm = 2.

Table 22. The regression models for the relationship between the square root transformed total content of potassium (Y) and bulk density (X) as well as effective cation exchange capacity (X).

Site type and layer²)		Regression				Analysis of variance	
		Constant	Regr. coeff.	T-value	R²	d.f.	F-value
		Bulk density					
Herb-rich	1	1.711	−0.0103	7.93***	0.583	1.45	62.83***
sedge mire	2	1.117	−0.0052	3.74***	0.368	1,24	13.97***
Ordinary	1	1.661	−0.0100	9.86***	0.491	1,101	97.30***
sedge mire	2	0.990	−0.0027	3.06***	0.091	1,94	9.39***
Small	1	1.396	−0.0069	4.28***	0.314	1,40	18.35***
sedge mire	2	0.936	−0.0048	2.52*	0.134	1,41	6.36*
		Effective cation exchange capacity					
Herb-rich	1	0.217	0.0239	4.14***	0.276	1,45	17.13***
sedge mire	2	model not significant					
Ordinary	1	0.585	0.0198	6.58***	0.300	1,101	43.27***
sedge mire	2	0.431	0.0116	4.07***	0.150	1,94	16.61***
Small	1	0.129	0.0265	4.28***	0.315	1,40	18.36***
sedge mire	2	−0.339	0.0278	5.58***	0.431	1,41	31.11***

²) 1=peat layer 0–10 cm, 2=peat layer 10–20 cm

here is directly correlated with the potassium content of peat. As previously mentioned (ch. 23. and 31.5) the potassium ion has for theoretical reasons been ignored when determining the basic cations. The error arising from this exclusion is minor, but antagonism between ions with different binding affinity can be of interest here. A high proportion of calcium and magnesium in the exchange complex may thus result in a low proportion of potassium, since the binding affinity of the former ions is considerably higher than that of the latter (SCHEFFER & SCHACHTSCHABEL 1976). The fact that the relationship between these three variables in the 10–20 cm layer is weaker can be attributed to the deficiency of potassium now being considerably stronger. Therefore, no clear dependence of potassium on either the cation exchange capacity or bulk density exists in this layer. The higher degree of humification in the lower layer can also have affected the relationships between the variables.

31. 9 Total content of calcium

The calcium content in peat varies from 1.10 mg/g to 8.90 mg/g calcium in the 0–10 cm layer and from 1.20 mg/g to 9.84 mg/g calcium in the 10–20 cm layer (Figure 17). With coefficients of variation between 28 and 45 per cent, the calcium distribution within the individual site types is thus more homogeneous than that of the potassium.

WARÉN (1924) and KOTILAINEN (1927) give for *Carex* and *Sphagnum* peat contents of the same magnitude as those reported here. KIVINEN (1933) states that the calcium content of peat varies considerably also; 90 per cent of the *Sphagnum* and *Carex-Sphagnum* peat investigated contained less than 7.15 mg/g calcium. According to VAHTERA (1955) the calcium content is in general lower in peat from drained peatlands than in peat from virgin areas. If comparing the frequency distributions for the two less fertile site types (Figure 17) with corresponding frequencies for the two mire sites in HOLMEN's (1964) investigation, this tendency can not be seen.

That forest drainage would negatively affect the calcium content of peat is somewhat surprising, since the uptake by forest trees is relatively modest. Further, in middle-aged pine stands 30–40 per cent of the amount annually taken up is returned to the soil in litter (cf. INGESTAD 1962, 1967, MÄLKÖNEN 1974). The increase in bulk density which generally occurs after drainage should lead to higher nutrient concentrations, not decrease them. Further, due to its preferencial binding affinity, the calcium ion is less likely to be leached as is the potassium ion.

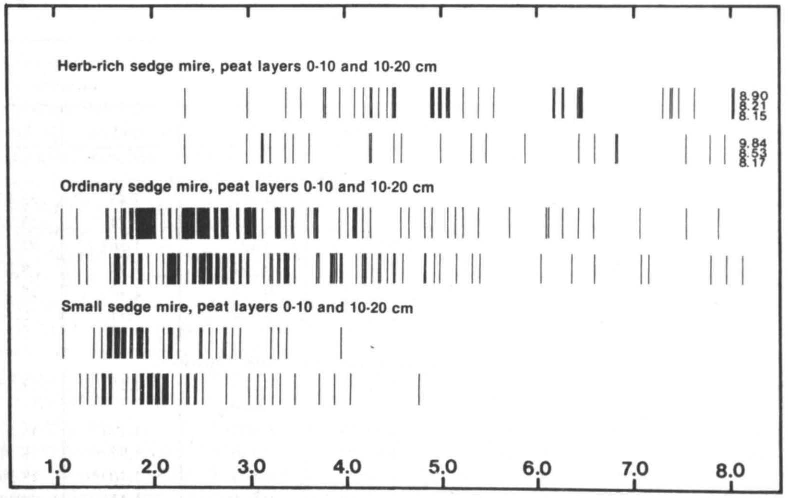

Figure 17. Total content of calcium in the peat samples.

Table 23. Mean total content of calcium in the peat samples.

Peat layer	Total content of calcium, mg/g		
	Herb-rich sedge mire	Ordinary sedge mire	Small sedge mire
0–10 cm	$5.28^{+0.23}_{-0.22}$ a	$2.86^{+0.12}_{-0.11}$ b	$2.09^{+0.11}_{-0.11}$ c
10–20 cm	$5.05^{+0.40}_{-0.37}$ a	$3.06^{+0.13}_{-0.13}$ b	$2.18^{+0.11}_{-0.10}$ c

The frequency diagrams (Figure 17) show a clear tendency towards increasing calcium content in peat in the site series from the least to the most fertile site type. In the upper layer the average contents rise from 2.09 mg/g to 5.28 mg/g calcium and in the lower layer from 2.18 to 5.05 mg/g calcium (Table 23). A two-way analysis of variance after logarithmic transformation shows statistically significant variations between the site types:

	Model of variance	Between site types	Between layers	Interaction
F-value	42.75***	53.38***	0.67	0.54
Degrees of freedom	5,350	4,350	3,350	2,350

Mean value testing verifies that the calcium content in both the layers increases from the small sedge mires to the ordinary sedge mires and further to the herb-rich sedge mires. The increase is 35 and 85 per cent in the upper layer and 40 and 65 per cent in the lower layer. Overall the calcium content is approximately 2.5 fold greater from the least to the most fertile site type.

Comparing the mean calcium contents (Table 23) with data given by VAHTERA (1955) for drained sedge mires, the two more fertile site types show 10 to 35 per cent lower contents than the virgin sites. The calcium content in peat from the small sedge mires is in both studies similar. Probably the post-drainage stand development does, after all, affect the calcium status of peat. As the stand development on fertile sites is faster than on poor sites, the calcium balance is on the former sites affected more strongly and sooner. On the other hand, HOLMEN (1964) gives for comparable mire sites mean calcium contents somewhat higher than those found here. Peat from mire sites in the fertility series next to those studied here contains on average 10.1 mg/g calcium (HEIKURAINEN 1953).

According to general opinion the calcium content in peat increases along with greater sampling depth (KAILA & KIVEKÄS 1956, HEIKURAINEN 1973b). This trend cannot be seen in this study. Examination of HOLMEN's (1964) material revals that the relationship does not exist in all the site types investigated by him For examples, in the profiles comparable to those investigated here the peat layer shows no definite change of calcium content with increasing depth in the profile. The same can be seen from results obtained by DAMMAN (1978) on ombrogeneous peatlands. It thus seems as if a positive correlation between calcium and sampling depth appears in profiles from sites where the content of total calcium is moderate.

The absolute amounts of calcium are presented in Figure 28. A two-way analysis of variance shows significant variations between the site types as well as between the two layers:

	Model of variance	Between site types	Between layers	Interaction
F-value	64.93***	70.32***	24.09***	1.67
Degrees of freedom	5,350	4,350	3,350	2,350

The average amounts, with the exception of those for ordinary and small sedge mires in the upper layer, differ significantly and follow the established quality gradient of the site series (Table 29). When examining by the site type the relationship between depth in profile and calcium, it appears that the absolute amount in all cases increases significantly from the upper to the lower layer. The change is of the magnitude 60, 80, and 35 per cent respectively in the series from the least to the most fertile site type.

The correlations between calcium and other site variables has been calculated in Tables 4—7. As already noted (ch. 31.4—5) the relationship with both pH and the proportion of basic cations in the exchange complex is clear. It is also characteristic that the calcium content in peat from the most fertile site type correlates with not only the degree of base saturation but also with the effective cation exchange capacity.

A strong positive relationship prevails between the contents of calcium and magnesium in peat (Figure 18, Table 24). Even if overflow surface water from the surrounding mineral soils is unlikely to affect the sites investigated it is, however, probable that this relation between calcium and magnesium levels is explained by the mineralogical composition of the surrounding and underlying soil (cf. RINDELL 1902). The influence of the mineral composition of the parent matter is still to be seen in the nutrient balance of the peat soil.

31.10 Total content of magnesium

The mangnesium contents in the peat samples examined range from 0.22 mg/g to 2.28 mg/g and from 0.10 mg/g to 1.95 mg/g magnesium in the 0—10 cm and 10—20 cm layers respectively (Figure 19).

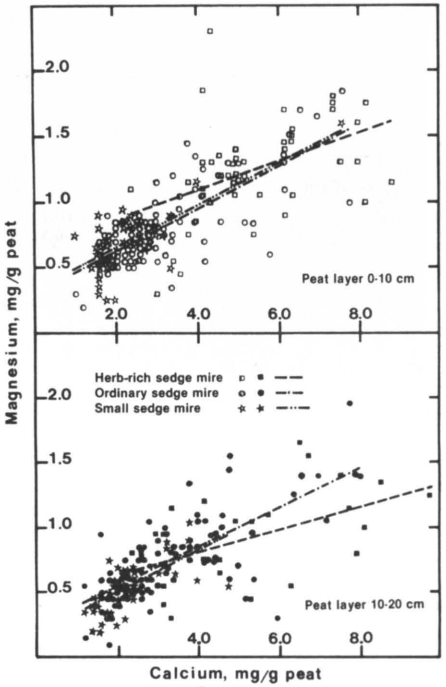

Figure 18. Scatter diagrams by layer showing the relationship between total contents of calcium and magnesium. For the mathematical models see Table 24.

WARÉN (1921) and WARÉN and KOTILAINEN (1922) give for *Sphagnum* peat, magnesium contents varying from 0.36 mg/g to 0.66 mg/g and for *Carex,* from 0.54 mg/g to 1.92 mg/g. BRENNER (1930) has, in samples from relatively fertile sites, obtained magnesium data between 0.18 mg/g and 1.80 mg/g magnesium. According to VAHTERA (1955) the content in *Sphagnum* peat varies considerably, from 0.08 mg/g to 3.47 mg/g magnesium. Since the peat investigated here probably corresponds to a series changing from *Sphagnum* peat towards *Carex* peat, the magnesium data in Figure 19 agree satisfactorily with the results referred to above.

Table 24. The regression models for the relationship between the total contents of calcium (X) and magnesium (Y).

Site type and layer¹)		Regression				Analysis of variance	
		Constant	Regr.coeff.	T-value	R²	d.f.	F-value
Herb-rich	1	0.649	0.1093	3.44***	0.209	1,45	11.87**
sedge mire	2	0.455	0.0904	3.07**	0.283	1,24	9.45**
Ordinary	1	0.307	0.1530	11.96***	0.586	1,101	143.07***
sedge mire	2	0.240	0.1502	10.09***	0.520	1,94	101.79***
Small	1	0.317	0.1645	6.35***	0.502	1,40	40.39***
sedge mire	2	0.183	0.1577	5.72***	0.444	1,41	32.78***

¹) 1=peat layer 0—10 cm, 2=peat layer 10—20 cm

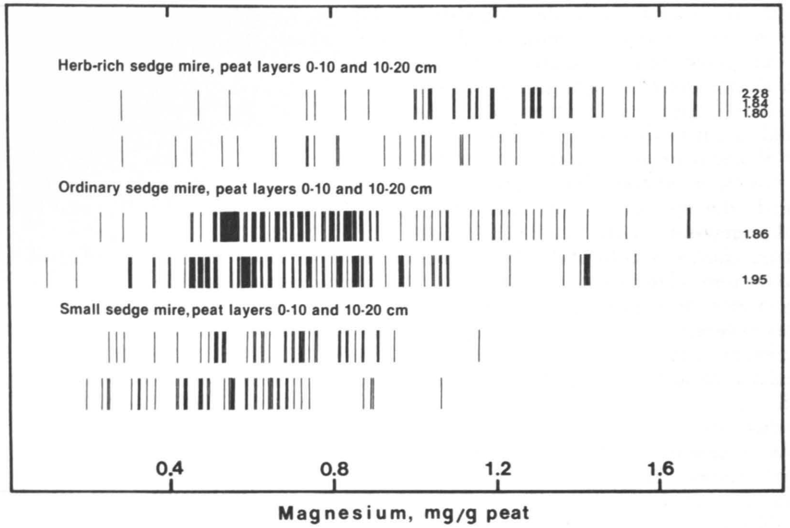

Figure 19. Total content of magnesium in the peat samples.

The average magnesium contents have been calculated in Table 25. In the 0—10 cm layer the mean values vary between 0.64 mg/g and 1.18 mg/g magnesium and in the 10—20 cm layer between 0.51 mg/g and 0.87 mg/g magnesium. A two-way analysis of variance of the logarithmically transformed data shows that the variation between the three site types and between the two peat layers is statistically significant:

	Model of variance	Between site types	Between layers	Interaction
F-value	23.18***	22.56***	6.78***	1.76
Degrees of freedom	5,350	4,350	3,350	2,350

Significance testing of the mean values show that the magnesium content, again with the exception of peat from the small and ordinary sedge mires, in the 0—10 cm layer parallels the site quality. In the upper layer the change from the two less fertile site types to the most fertile is of the magnitude 60—80

Table 25. Mean total content of magnesium in the peat samples.

Peat layer	Total content of magnesium, mg/g		
	Herb-rich sedge mire	Ordinary sedge mire	Small sedge mire
0—10 cm	$1.18^{+0.065}_{-0.062}$	$0.75^{+0.027}_{-0.026}$ a $\underline{\text{b}}$	$0.64^{+0.038}_{-0.036}$ b c
10—20 cm	$0.87^{+0.014}_{-0.014}$ $\underline{\text{a}}$	$0.68^{+0.032}_{-0.031}$ b $\underline{\text{c}}$	$0.51^{+0.031}_{-0.029}$

per cent. In the lower layer the magnesium content in the site series increases gradually by, in both cases, approximately 30 per cent.

This clearly defined relationship between magnesium in peat and timber production potential is interesting in comparison with results obtained in previous studies. WARÉN (1924) has observed no such regular relationship with the species composition of the ground vegetation. VAHTERA (1955) states that magnesium in peat from the drained sites studied by him relates very poorly to the site quality index and gives for sedge mires contents between 0.38 mg/g and 0.64 mg/g. The ordinary sedge mires showed the lowest magnesium content of all the site types studied.

Comparison to the present results reveals that the magnesium balance in peat from both the drained and undrained small sedge mires is the same. In peat from the two more fertile sites, the content after drainage seems to be approximately 50 per cent lower. Possibly the regulation of soil water has caused leaching losses of magnesium ions, the binding affinity of which is intermediet in comparison with calcium and potassium. Since the magnesium uptake by pine is of the same magnitude as its calcium uptake (INGESTAD 1962, 1967), vigorous tree stand growth after drainage could also reduce the magnesium contents considerably below the pre-drainage levels.

The relationship between the absolute amounts of magnesium and the site type is about the same as shown above for the contents (Figure 28). A two-way analysis of variance after logarithmic transformation of the amounts shows that the variation between site types as well as between the two layers is significant:

	Model of variance	Between site types	Between layers	Interaction
F-value	45.47***	53.59***	11.04***	3.57*
Degrees of freedom	5,350	4,350	3,350	2,350

Unfortunately including the bulk density has caused a significant interaction between both the classifying factors, which impairs the validity of the statistical tests (Table 29). The differences in the mean absolute magnesium amounts (Figure 28, Table 29) between the most fertile site type and the two others is now considerably bigger, which is explained by the high bulk density of peat from the former site type (Table 8).

The relationship between sampling depth and magnesium in peat is interesting. The concentration content in peat from the small and ordinary sedge mires decreases significantly by 20–25 per cent from the upper to the lower layer (Table 25). On the other hand, when examining the absolute amounts (Figure 28) the trend is the opposite. The increase is significant, however, only in peat from the ordinary sedge mires (Table 29). The same tendencies have been noted by KAILA and KIVEKÄS (1956). According to them, there prevails a positive relationship between extractable magnesium and depth in profile when the results are given on the basis of volume. Data based on sample weight, on the contrary, seem to give a tendency towards negative relationship in the surface peat layer. DAMMAN (1978) has obtained results indicating unchanged magnesium contents along with increasing depth in profile. The magnesium figures found in the studies mentioned are of the same magnitude as the data obtained here.

When examining the relationship between magnesium in peat and the other site variables (Tables 4–7) one can observe that the correlations follow the same pattern as shown for calcium. This is to be expected because of the similar chemistry of the two divalent ions.

32. External factors affecting the physical and chemical properties of peat

32.1 Microtopography of the mire plane

The site types included in this study are characterized by a ground vegetation composed of plant communities showing features of tree covered as well as treeless peatlands. The mire plane belongs to the latter vegetation type and the more or less pronounced hummocks to the former (cf. HEIKURAINEN 1973b). On the sample plots in this study the average height difference between hummock surface and mire plane surface is 23, 20 and 32 cm in the series from the least to the most fertile sites. Consequently, one can assume that the variation within site type vegetation due to this microtopographic effect is reflected in the properties of the peat fromed (cf. HEIKURAINEN 1953). According to KIVINEN (1933, 1934), the chemical composition of the peat-forming plants varies within a relatively wide range. Thus, the surface peat is heterogeneous already through definition of the sedge mires.

However, when dividing the sample material into two classes, humocks and mire plane, and comparing the class means separately for each site type, one finds that peat from hummocks does not differ from peat from the mire plane. The reason for there being no differences is undoubtedly related to the limited number of hummock samples. Altogether, only 20 of the sample points are located on clearly marked hummocks, and are unevenly distributed between the three site types:

herb-rich sedge mire	3	sample	plots
ordinary sedge mire	8	”	”
small sedge mire	9	”	”

Thus any differences arising from microtopography are masked by the large within site type variation shown by all the variables. It should also be pointed out that the relationships obtained above (ch. 31) between site variables and site type are not affected by this stratification.

In order to limite the within site type variation the samples representing hummocks were compared to the adjacent sample plots from the mire plane. In cases where no sample from the mire plane within the same peatland area was available a sample plot from the nearest comparable site was used. Means were calculated after classifying the material according to site type and peat layer (Figures 20, 21). Significance testing of the means by a paired t-test showed no regular differences between hummocks and mire plane.

The result is somewhat surprising, as the species composition of the corresponding peat-forming plant communities differs considerably from each other. The explanation must again be sought in the sample material. Firstly, the number of sample plots is still very limited and, secondly, the plots were not taken as adjoining pairs of hummock and mire plane, but independently within the peatland area. This implies that differences in peat properties between hummocks and mire plane still are masked by within site type variation.

HEIKURAINEN (1953) has found on eutrophic pine mires in north Finland that peat from the mire plane has a higher pH and calcium content than that from hummocks. The same trend could be seen for nitrogen and potassium. DAMMAN (1978) has also recorded certain differences between peat from hummocks and mire plane. Accordingly, most elements occur with higher concentrations in the surface peat of the mire plane than in that of the hummocks. In contrast with HEIKURAINEN's (1953) result DAMMAN's (1978) investigation reagards extremely ombrogeneous sites with *Sphagnum fuscum* hummocks and a *Sphagnum magellanicum* blanket in the bottom vegetation layer of the mire plane. However, neither of the above mentioned studies present any statistical evidance as a basis for their conclusions.

Although no statistically provable relationship between the peat properties and the microtopography could be found, the relative changes of the variables from mire plane to hummock were calculated (Table 26). The electric conductivity in peat from all the site types seems to increase from mire plane to hummock. Of the other site factors only pH shows uniformity in the site type series indicating no change in soil acidity from mire plane to hummock. In peat from the two less fertile site types potassium, calcium, and magnesium contents tend to be higher in samples from hummocks.

32.2 Variations arising from the geographic location of the site

The peatlands studied are spread over a wide latitude range from 60° to 66° N (Figure 1). Climate as well as the properties of bedrock and mineral soil vary considerably within this geographic amplitude, which may influence on the physical and chemical properties of the organic soils. The question

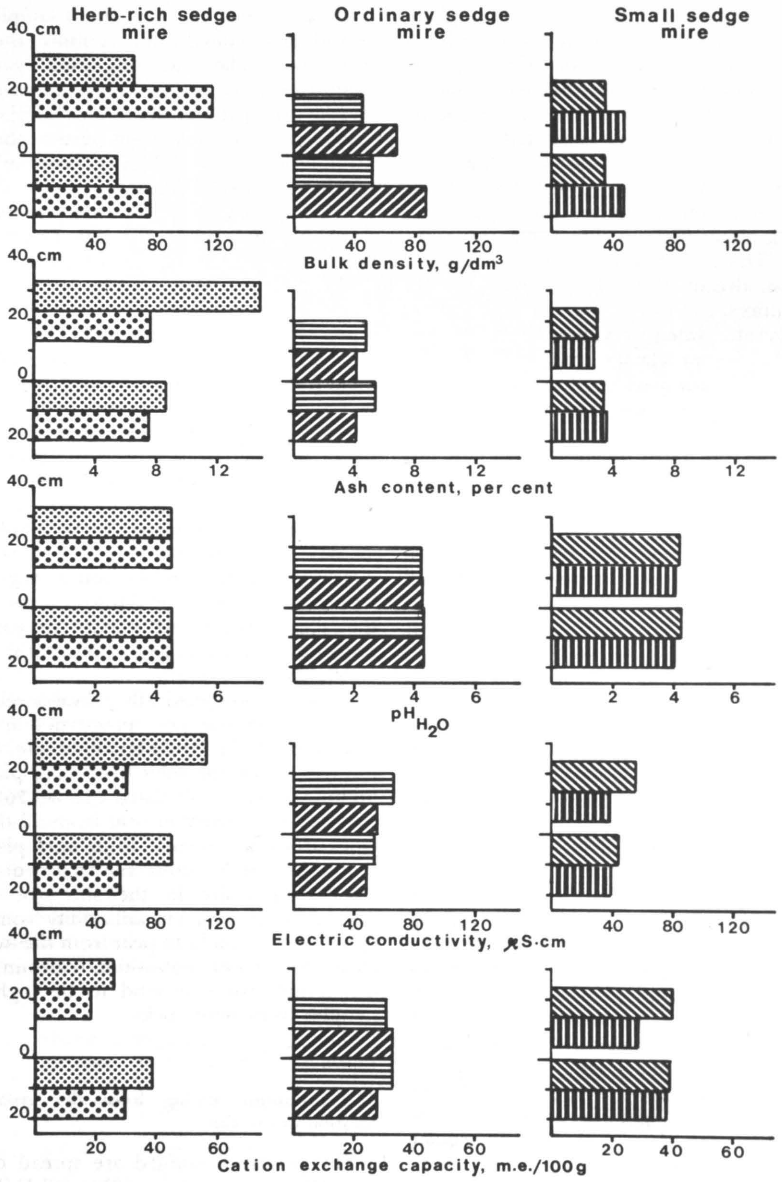

Figure 20. Average bulk density, ash content, acidity, electric conductivity, and cation exchange capacity of peat samples from hummocks and adjacent mire plane respectively.

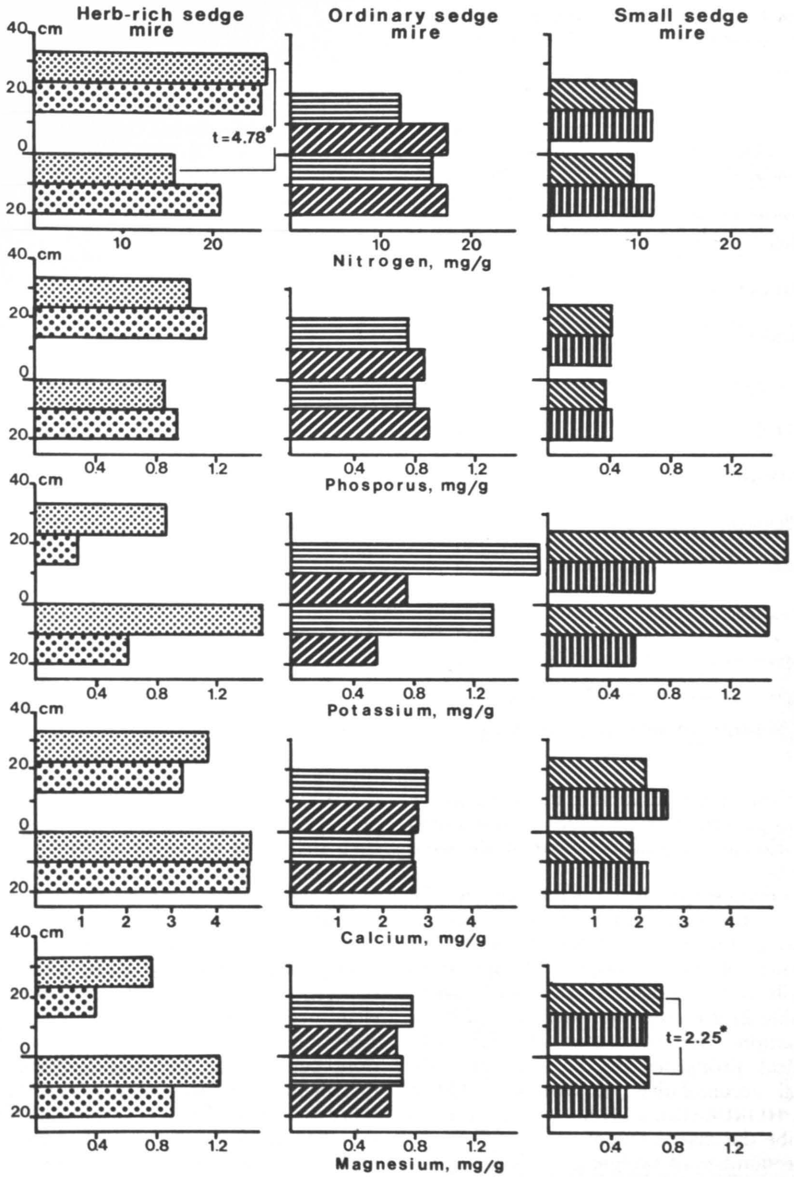

Figure 21. Average total contents of macronutrients in peat samples from hummocks and adjacent mire plane respectively.

Table 26. Relative change from mire plane to hummock in physical and chemical properties of peat. Differences significant at 5 per cent risk level marked with asterisk.

Variable and layer[1]		Relative change from mire plane to hummock, per cent		
		Herb-rich sedge mire	Ordinary sedge mire	Small sedge mire
Bulk density	1	+ 20	− 11	± 0
	2	+ 51	− 23	± 0
Ash content	1	+ 83	− 13	− 15
	2	± 0	± 0	− 23
Acidity	1	± 0	− 2	− 2
	2	± 0	− 3	± 0
Electric cond.	1	+ 26	+ 25	+ 26
	2	+ 5	+ 16	+ 2
C.E.C.	1	− 32	− 8	+ 2
	2	− 39	+ 17	− 25
Nitrogen	1	+ 65*	− 22	+ 1
	2	+ 21	± 0	− 1
Phosphorus	1	+ 20	− 5	+ 8
	2	+ 21	− 11	± 0
Potassium	1	− 43	+ 24	+ 8
	2	− 52	+ 35	+ 19
Calcium	1	− 10	+ 11	+ 14
	2	− 31	+ 2	+ 19
Magnesium	1	− 36	+ 8	+ 15*
	2	− 57	+ 7	+ 27

[1] 1=peat layer 0–10 cm, 2=peat layer 10–20 cm

then rises wheter this kind of influence can be seen in peat from geographically widespread vegetation associations belonging to the same site type.

The main emphasis in the following will be laid on the relationship between macroclimate and properties of peat. However, the influence of the lithology, although most difficult to distinguish, will also be discussed. In Table 27 are presented coefficients for the correlation between the physical and chemical properties of the peat and the annual accumulative temperature (SARVAS 1972, HEIKURAINEN 1973a), which is used to describe the macroclimate.

The number of sample plots representing herb-rich and small sedge mires are unevenly distributed along the climatic gradient. Especially in the case of the latter sites, the regressions in the 1 100–1 300 degree days interval are determined by only a few observations, the representativeness of which can be questioned. The same interval is perhaps over-represented in the case of the herb-rich sedge mires. Thus, emphasis in the following is placed on the ordinary sedge mires. These also comprise the biggest class with altogether 104 sample plots.

Table 27 shows that among the ordinary sedge mires there are clear relationships between climate and bulk density, pH, electric conductivity, cation exchange capacity and content of potassium. Significant correlations between the variables mentioned and macroclimate appear also within the two other site types. The strongest linear relationship is found for potassium, which also in the herb-rich and small sedge mires shows significant negative correlations. A negative linear relationship also prevails with the degree of acidity and cation exchange capacity, while the bulk density and the electric conductivity of peat increase along with increasing accumulative temperature.

Table 27. Simple correlations between annual accumulative temperature and physical and chemical properties of peat.

Site type and layer[1]		Number of observations	Correlations with annual accumulative temperature											
			Bulk density	Vol. weight org. matter	Ash content	Acidity	Electric cond.	C.E.C.	Base saturation	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Herb-rich	1	47	0.59	− 0.22	− 0.21	− 0.06	0.17	− 0.19	0.37	0.04	0.06	− 0.56	0.03	0.16
sedge mire	2	26	0.12	− 0.02	0.09	0.18	− 0.01	− 0.09	−0.04	− 0.34	0.04	− 0.34	0.11	0.15
Ordinary	1	103	0.26	− 0.16	− 0.19	− 0.37	0.25	− 0.43	0.10	0.00	0.22	− 0.41	0.17	0.16
sedge mire	2	96	0.25	− 0.10	− 0.09	− 0.27	0.32	− 0.41	0.11	− 0.14	0.11	− 0.68	0.11	0.17
Small sedge	1	42	− 0.07	0.03	0.18	− 0.35	0.24	− 0.26	0.00	0.08	0.24	− 0.21	0.31	0.22
mire	2	43	0.07	0.12	0.18	− 0.18	0.21	− 0.28	− 0.07	− 0.04	0.08	− 0.51	0.11	0.26
All types	1	192	0.38	0.00	0.12	− 0.10	0.43	− 0.37	0.42	0.23	0.41	− 0.40	0.40	0.38
All types	2	165	0.26	0.07	0.11	− 0.15	0.35	− 0.36	0.23	0.01	0.27	− 0.51	0.22	0.28
All types	3	357	0.27	0.01	0.12	− 0.08	0.39	− 0.36	0.34	0.09	0.34	− 0.31	0.32	0.35

[1] 1=peat layer 0–10 cm, 2=peat layer 10–20 cm, 3=peat layer 0–20 cm

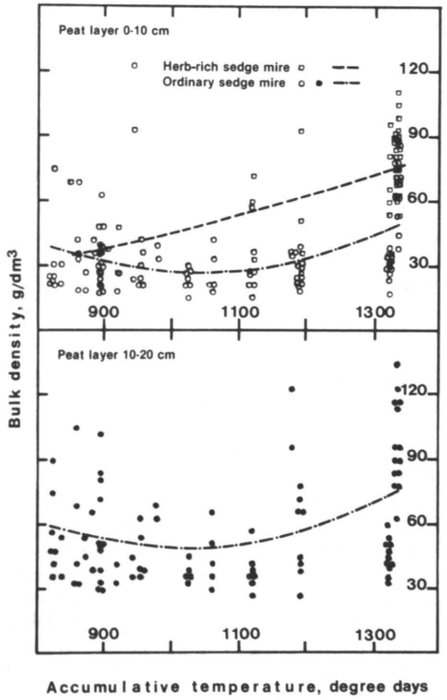

Figure 22. Scatter diagrams by layer showing the relationship between annual accumulative temperature (dd) and bulk density of peat. For the mathematical models see Table 28.

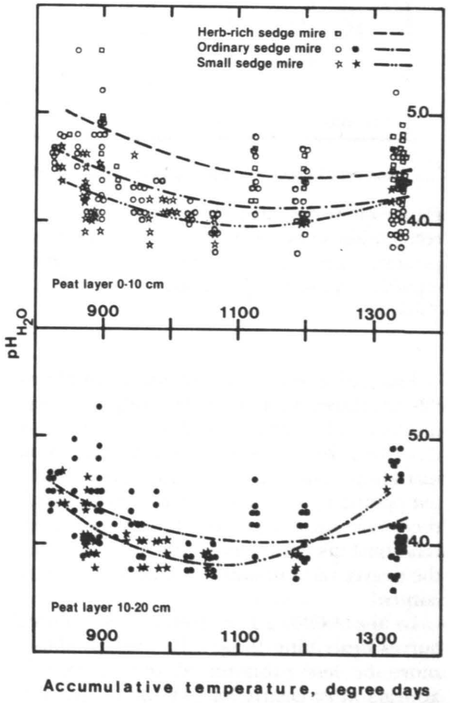

Figure 23. Scatter diagrams by layer showing the relationship between annual accumulative temperature (dd) and acidity of peat. For the mathematical models see Table 28.

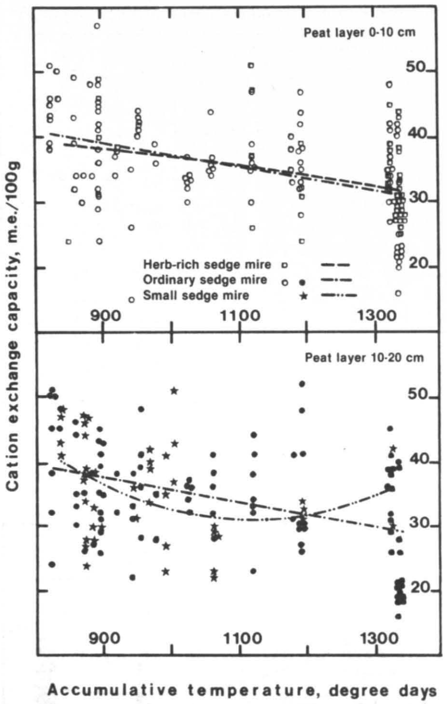

Figure 24. Scatter diagrams by layer showing the relationship between annual accumulative temperature (dd) and effective cation exchange capacity of peat. For the mathematical models see Table 28.

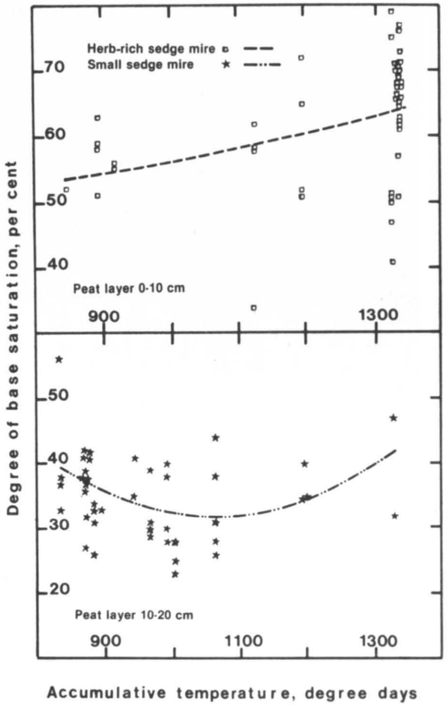

Figure 25. Scatter diagrams by layer showing the relationship between annual accumulative temperature (dd) and degree of base saturation in peat. For the mathematical models see Table 28.

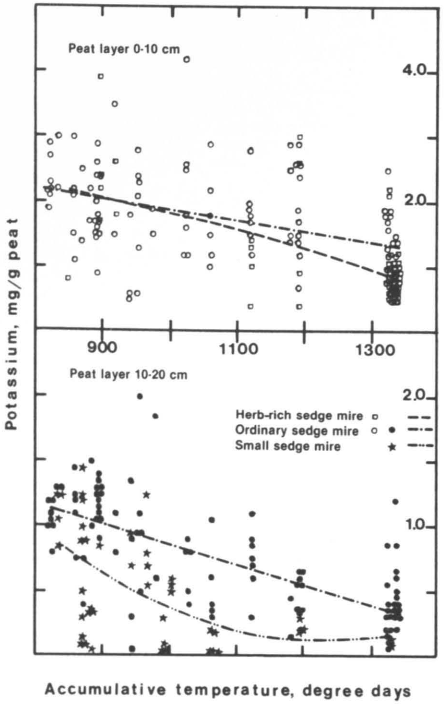

Figure 26. Scatter diagrams by layer showing the relationship between annual accumulative temperature (dd) and total content of potassium in peat. For the mathematical models see Table 28.

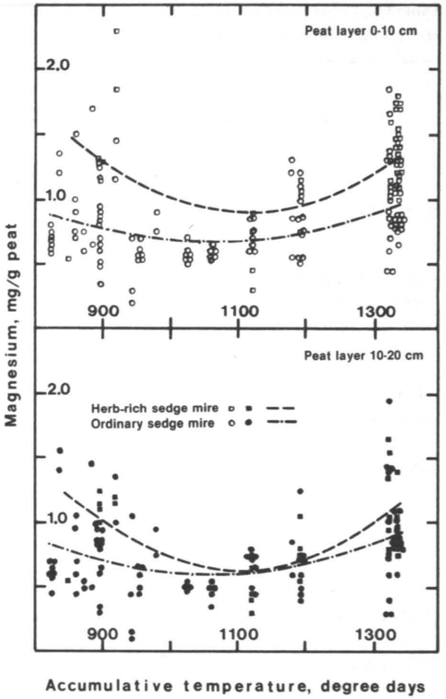

Figure 27. Scatter diagrams by layer showing the relationship between annual accumulative temperature (dd) and total content of magnesium in peat. For the mathematical models see Table 28.

Examining the scatter diagrams in Figures 22–27 shows that the relationsips are in a number of cases non-linear and better described by a second degree polynomial including both the annual accumulative temperature and its square. Accordingly, there are now also significant non-linear relationships between macroclimate and both the degree of base saturation and magnesium content.

In the 1 000–1 200 degree days interval, curves describing these relationships show a more or less pronounced minimum. This appears most clearly for pH and magnesium. The coefficients and the statistical test values for the regression models formed are presented in Table 28. The degrees of explanation are in most cases relatively modest, between 10 and 20 per cent. This result is, however, quite satisfactory when taking into account that the macroclimate is only one of many factors affecting peat properties.

In cases where the site factors are influenced by the macroclimate there are only a few regressions showing a linear or an almost linear relationship. Some of them, however, indicate a trend towards a positive or negative relationship. The question then rises whether climate is the primary independent variable. In particular when the regressions indicate a minimum one can imagine that other factors than the climate would better describe the variations.

In the geographic region corresponding to the inflexion points of the curves the bedrock mainly consists of granite diorite and quartz diorite. Sample plots in the northern climatic area, with a few exceptions, are situated on granitic gneiss. In the southern part of the country the composition of the bed-rock varies, but can as in the two other regions be classified into acidic rock (cf. Figure 1, SIMONEN 1964). In the few cases where the peatlands sampled fell in areas with basic or ultra-basic lithologies (8 sample plots), the site type was no "better" than ordinary sedge mire.

It must be added that the soil class in the southern area largely belongs to the clay and silty soils (OKKO 1964). This possibly influences the quality of soil water and thereby also the properties of adjacent peatlands. However, it can be concluded that the bedrock would not be a better independent variable in the regression models presented (Table 28) than the macroclimate.

When examining the individual relationships between macroclimate and the site variables one finds that the bulk density of peat in the upper layer from the herb-rich sedge mires increases along with increasing annual accumulative temperature. In peat from the ordinary sedge mires the trend is not fully clear. In the 800–1 000 degree days interval the bulk density data shows a markedly skewed distribution. A number of clearly individual observations between 60 and 120 g/dm^3 have certainly influenced the regression curve.

The strong correlation within the most

Table 28. The regression models for the relationships between annual accumulative temperature (X,X^2) and physical and chemical properties of peat (Y).

Site type and layer[1])		Regression						Analysis of variance	
		Constant	Regr.coeff. X	T-value	Regr.coeff. X^2	T-value	R^2	d.f.	F-value
					Bulk density				
Herb-rich sedge mire	1	6.074	–	–	3.90x10^{-5}	5.08***	0.364	1,45	25.77***
Ordinary sedge mire	1	294.040	–0.5139	3.13***	2.48x10^{-4}	3.31***	0.160	2,100	9.53***
– " –	2	319.800	–0.5286	2.06*	2.59x10^{-4}	2.21*	0.109	2,93	5.71**
					Acidity				
Herb-rich sedge mire	1	11.063	–0.0110	2.47**	4.55x10^{-6}	2.31*	0.272	2,44	8.24***
Ordinary sedge mire	1	9.863	–0.0097	3.43***	4.11x10^{-6}	3.18***	0.214	2,100	13.58***
– " –	2	10.988	–0.0122	4.12***	5.32x10^{-6}	3.96***	0.207	2,93	12.12***
Small sedge mire	1	11.137	–0.0129	3.80***	5.81x10^{-6}	3.62***	0.343	2,39	10.16***
– " –	2	15.747	–0.0223	7.64***	1.04x10^{-5}	7.53***	0.599	2,40	29.93***
					Cation exchange capacity				
Herb-rich sedge mire	1	43.433	–	–	6.17x10^{-6}	2.29*	0.104	1,45	5.23*
Ordinary sedge mire	1	55.904	–0.0183	4.74***	–	–	0.182	1,101	22.46***
– " –	2	54.616	–0.0188	4.31***	–	–	0.165	1,94	18.57***
Small sedge mire	2	174.505	–0.2548	2.09*	1.13x10^{-4}	1.96*	0.158	2,40	3.75*
					Degree of base saturation				
Herb-rich sedge mire	1	46.348	–	–	1.00x10^{-5}	2.71**	0.141	1,45	7.37**
Small sedge mire	2	191.479	–0.3001	2.91***	1.41x10^{-4}	2.88**	0.177	2,40	4.29*
					Content of potassium				
Herb-rich sedge mire	1	3.109	–	–	1.26x10^{-6}	4.94***	0.352	1,45	24.45***
Ordinary sedge mire	1	3.519	–0.0016	4.46***	–	–	0.165	1.101	19.94***
– " –	2	2.404	–0.0015	8.97***	–	–	0.461	1,94	80.44***
Small sedge mire	2	7.667	–0.1230	1.97*	5.01x10^{-6}	1.69*	0.313	2,40	9.10***
					Content of magnesium				
Herb-rich sedge mire	1	11.604	–0.0192	3.00***	8.63x10^{-6}	3.02***	0.185	2,44	4.99*
– " –	2	11.610	–0.0200	3.36***	9.09x10^{-6}	3.42***	0.352	2,23	6.26**
Ordinary sedge mire	1	4.663	–0.0075	2.94***	3.56x10^{-6}	3.05***	0.110	2,100	6.18**
– " –	2	5.259	–0.0088	3.14***	4.14x10^{-6}	3.24***	0.127	2,93	6.77**

[1]) 1=peat layer 0–10 cm, 2=peat layer 10–20 cm

fertile site type is partly due to the peat from a number of additional sample plots (Figure 1) showing a high bulk density ($\bar{x}$ = 81.8 g/dm^3). When comparing with average data for the rest of the sample plots ($\bar{x}$ = 60.6 g/dm^3) in the same climatic region (> 1 000 dd) one finds a significant difference (t_{19} = 3.64***). However, even when excluding these additional samples, peat from the southern region show a higher bulk density than peat from the northern region. ($\bar{x}$ = 34.4 g/dm^3) (WESTMAN 1979b).

To what extent this difference in bulk density originates from a higher decomposition degree of peat in the southern region, or whether it arises from a change in the composition of peat cannot be decided. It is worth taking into account that the sample plots in the southern region have in general a more developed tree stand than those in the north. This may result in a larger proportion of woody peat affecting the peat properties. However, the volume weight of the organic matter does not show any relationship with the climatic gradient (Table 27).

The effective cation exchange capacity of peat is, without any doubt negatively correlated with the macroclimate. The degree of acidity, on the other hand, shows, a non-linear regression which, at least in the upper layer indicates a tendency towards a negative relationship (Figures 23, 24, Table 28). Because of the connection between the two variables (Tables 5–7, ch. 31.4, 31.5) one can also expect them to react similarly for variations in the macroclimate. With all probability the humification process is climate dependent; low temperatures and high humidity have a definite negative influence on the microbial activity in soil (cf. MIKOLA 1960, LÄHDE 1974). Even purely chemical processes are directly affected by temperature and water supply. As a consequence, the humus products built up under different climatic conditions may differ to their chemical properties. For instance, at approximately equal bulk density, the proportion of acid equivalents may vary as can also the acid strength of the organic matter. This is a plausible reason for the negative trends shown by effective cation exchange capacity. Correlation with bulk density can also explain some of the climate dependence of the cation exchange capacity (cf. Tables 5–7, 27, ch. 31.5). The species composition of surface vegetation shows a climate dependence (Table 1), which can have an additional influence on the variation of exchange capacity of peat (cf. PUUSTJÄRVI 1956).

The same factors which connect the cation exchange capacity to the climate probably also influence the soil pH. However, since fresh plant material was included in samples from the upper peat layer, the non-linear relationship in this case can have a connection with the physiological activity of the soil flora and fauna. Under the severe climatic conditions of northern Finland root activity had more or less stagnated at the time of sampling (August), while root growth and nutrient uptake still took place under the more favourable conditions of southern Finland (cf. SCHEFFER & SCHACHTSCHABEL 1976). Similarly, the microbial activity culminates at different times in north and south Finland.

The relationship between macroclimate and the nutrient content of peat has been examined by dividing the same sample material into two climatic regions with the annual accamalative temperature 1 000 degree days as a limit (WESTMAN 1979a). It was established that the potassium content of peat in the southern region was significantly lower than that in the northern region. The opposite held for the nitrogen content in peat from the herb-rich and ordinary sedge mires. LUNDMARK (1974) has in investigations on forest soil raw humus in Sweden found similar gradients for the two nutrients.

When examining the corresponding correlations on the basis of Table 27 one finds that potassium in most cases is significantly negatively correlated with the annual accumulative temperature, while no correlation prevails in the case of nitrogen. The explanation for the lack of correlation in the latter case, although WESTMAN (1979a) has shown significant differences between the two regions, must be due to the considerable variation of the nitrogen data. As there is no ecological basis for dividing at 1 000 degree days either, the trend obtained can be a result of non-climatic random effects. On the other hand, it is conceivable that a larger sample material distributed evenly over the geographic range would better illustrate a relationship.

The clear negative correlation between the macroclimate and the content of potassium can no doubt largely be explained by correlation with the cation exchange capacity (cf. Tables 4–7, 27, ch. 31.8). Differences in the peat forming plant community (cf. Table 1) as well as in the site requirements of plants and thereby changed nutrient uptake (Damman pers. comm.) can also contribute to the climate dependent variations of potassium. On the other hand, potassium is the most mobile nutrient cation in peat (cf. STARR & WESTMAN 1978, MANNERKOSKI 1980), and therefore an additional input with moving soil water could be likely. However, contamination with underlying and surrounding mineral soil should affect also other mineral nutrients and in particular the ash content of peat. Of these only the magnesium content is clearly related to the climate and shows a clear but unexplainable minimum in the degree days interval 1 000–1 200. It must further be pointed out that there exists no relationship between potassium content and accumulative temperature in peat from the herb-rich sedge mires, the most minerogeneous of the three site types.

33. The relationship between soil nutrient status and timber production capacity of the sites studied

33.1 The absolute amounts of macronutrients in peat in relation to tree growth requirements

The average absolute amounts of nutrients in peat from the three site types have been calculated separately for both peat layers (Figure 28). Statistical testing (Table 29, ch. 31.6–10) shows that the absolute amounts follow the same gradients as shown for the corresponding concentration contents. It is of special importance for the subsequent discussion that the potassium data, when expressed in absolute figures, follows the established quality gradient of the site series and that the difference between the two peat layers is levelled. For the other nutrients the difference between the two layers is now more pronounced.

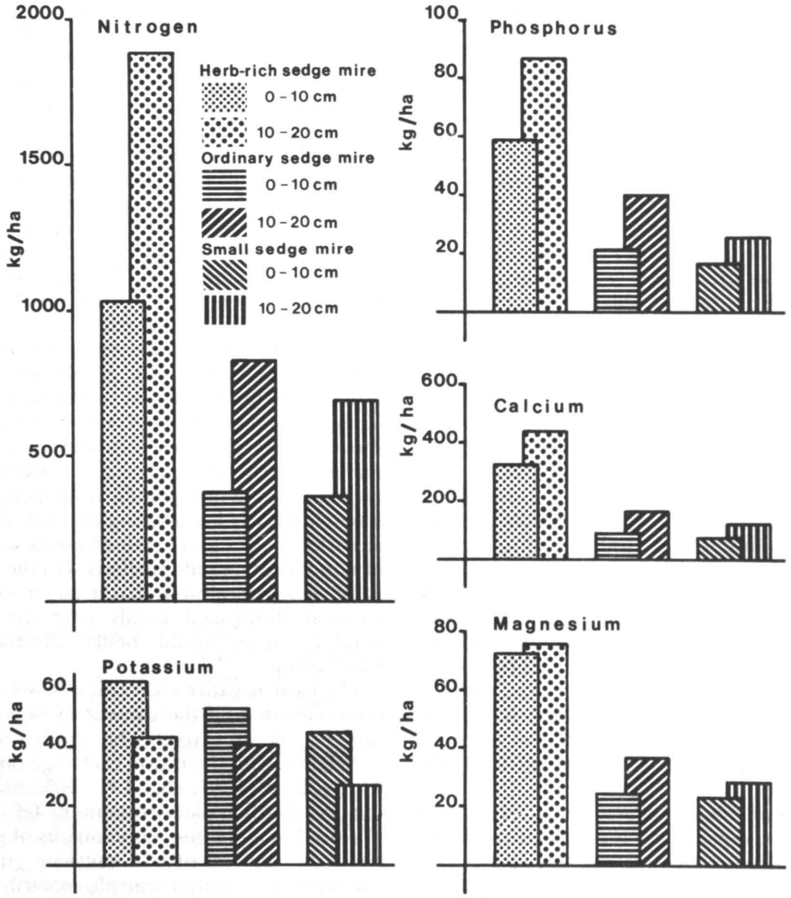

Figure 28. Histograms showing the average absolute amounts of macronutrients in surface peat from the sedge mires.

Table 29. Critical D-values at 5 % risk level from the Student-Newman-Keul's test of the average absolute amounts of macronutrients in peat (Figure 28).

Critical D-values, kg/ha	[1]		Herb-rich sedge mire 1	Herb-rich sedge mire 2	Ordinary sedge mire 1	Ordinary sedge mire 2	Small sedge mire 1	Small sedge mire 2
Herb-rich	1	Nitrogen	–	500	262	209*	311	280
sedge mire	2			–	579	533	692	634
Ordinary	1				–	159	78*	141
sedge mire	2					–	218	171*
Small	1						–	193
sedge mire	2							–
Herb-rich	1	Phosphorus	–	22	14	11	13	15
sedge mire	2			–	26	24	31	28
Ordinary	1				–	7.3	4.5	5.0*
sedge mire	2					–	10	7.9
Small	1						–	6.8
sedge mire	2							–
Herb-rich	1	Potassium	–	3.1	4.3	5.5	4.5	6.0
sedge mire	2			–	3.2	4.4	3.2	4.6
Ordinary	1				–	4.4*	3.7	4.9
sedge mire	2					–	3.9	5.0
Small	1						–	3.2
sedge mire	2							–
Herb-rich	1	Calcium	–	104	74	58	91	79
sedge mire	2			–	126	111	145	133
Ordinary	1				–	28	17*	22
sedge mire	2					–	39	30
Small	1						–	30
sedge mire	2							–
Herb-rich	1	Magnesium	–	17*	15	12	19	17
sedge mire	2			–	20	18	24	22
Ordinany	1				–	5.9	4.2*	4.8*
sedge mire	2					–	8.1	6.3
Small	1						–	6.6*
sedge mire	2							–

[1] 1=peat layer 0–10 cm, 2=peat layer 10–20 cm.

The mean absolute amount of nitrogen calculated for both sampling layers together increases from 1 060 kg/ha to 1 210 kg/ha and to as much as 2 920 kg/ha in the site series from the least to the most fertile site type. HOLMEN (1964) has for comparable sites found nitrogen amounts of 1 000 and 4 500 kg/ha respectively in a 20 cm deep peat layer. Compared with mineral soils where nitrogen supply most often is growth limiting (cf. ALBREKTSSON et al. 1977), the nitrogen status in peat soils has been considered adequate. However, the nitrogen data in Figure 28 do not differ greatly from the amounts given by VIRO (1969) for mineral forest soils in south Finland. Accordingly, the nitrogen amount in the raw humus layer varies between 430 and 620 kg/ha and in a 30 cm deep mineral soil layer between 1 910 and 2 930 kg/ha.

Whether a nitrogen amount of between 1 000–3 000 kg/ha/ and 20 cm is sufficient for continuous timber production, can be discussed. HJERTSTEDT (1936) considers amounts between 8 000 and 10 000 kg/ha and 20 cm moderate for agriculture while HOLMEN (1969) gives values between 2 000 and 3 000 kg/ha and 20 cm as the minimum requirement for timber production on drained peatlands. SEPPÄLÄ and WESTMAN (1976) have measured increased stand growth after nitrogen fertilization on drained sedge pine mires and eutrophic sedge pine mires in north Finland, the nitrogen supply of which is considered satisfactory, and even good. The mean amount of nitrogen in the 20 cm deep surface peat layer from the experimental fields was 2097 ± 539 kg/ha. On the basis of the average values (Figure 28) and data given in literature it seems that only the most fertile site type show a nitrogen status allowing forest production without application of commercial fertilizers.

When examining the phosphorus and potassium amounts, which are generally considered as the most growth limiting nutrients on drained peatlands (e.g. HUIKARI & PAAVILAINEN 1972), one finds that the absolute amounts in the topmost peat layer increase in the site series from the least to the most fertile sites: 42, 62 and 146 kg/ha phosphorus and 74, 97 and 107 kg/ha potassium, respectively.

Compared with mean amounts, 260 and 490 kg/ha phosphorus reported by KAILA (1956a), the amounts found here must be considered very low. Kaila has obviously transformed the nutrient contents into absolute amounts by using artificial laboratory bulk densities. This generally results in overestimation of the absolute amounts. HOLMEN (1964) gives 60 and 150 kg/ha phosphorus for two drained mire sites and considers (HOLMEN 1969) that 150 kg/ha in a 20 cm layer is a minimum for continuous timber production. In relation to this minimum requirement, the phosphorus amounts found here are still low, in particular, in peat from the two less fertile sites. The amount of phosphorus in peat from the small sedge mires is only a third of the minimum limit mentioned above. The phosphorus deficiency is enhanced by most of it being fixed in organic form (KAILA 1956a). According to SEPPÄLÄ and WESTMAN (1976) on sedge mires in north Finland with an average amount of phosphorus of 134 ± 35 kg/ha stand growth responses to an application of phosphorus fertilizers.

Related to the potassium amounts given by HEIKURAINEN (1953) for north Finnish eutrophic pire mires in the vegetation continuum next to the sedge mires, potassium amounts in this study are relatively small. HOLMEN (1964) gives, on the other hand, for the drained sites mentioned above, 50 and 110 kg/ha potassium, suggesting 100 kg as a minimum requirement for forest production (HOLMEN 1969). According to the data in Figure 28, again only the herb-rich sedge mires exceed this limit. When taking into account the annual potassium uptake, which in 28 to 45 year old pine stands on mineral soils varies between 10 and 18 kg/ha (MÄLKÖNEN 1974), one can ask the question if even the minimum amount given by Holmen is sufficient. However, potassium application has had no effect on stand development in the fertilization experiment described by SEPPÄLÄ and WESTMAN (1976). On the experimental fields the average amount of potassium in peat was no higher than 81 ± 4 kg/ha. On the other hand the main part of the potassium in peat is bound in easily extractable from (KAILA & KIVEKÄS 1956, STARR & WESTMAN 1978). Thus, normal stand growth may continue until a sudden decrease in potassium supply causes a total dieback.

It is evident that only in peat from the herb-rich sedge mires the three most important macronutrients show a balance which is satisfactory with regard to continuous timber production. Against this it is interesting that productivity studies (HEIKURAINEN 1959, 1972, HEIKURAINEN & SEPPÄLÄ 1973, KELTIKANGAS & SEPPÄLÄ 1973) as well as practical experience show that the tree stand without fertilizer application on the three site types investigated develops well after drainage. When comparing these peatland site types with mineral soil forest site types, the stand increment of ordinary and small sedge mires is 77 and 50 per cent respectively of that on *Myrtillus* site types in south Finland. The stand development on the herb-rich sedge mires is even more advantageous (e.g. HEIKURAINEN 1959). Consequently, it seems as if HOLMEN's (1969) minimum requirements were placed somewhat on the higher side. However, HOLMEN's (1964, 1969) minimum requirement levels were estimated on the basis of data from only one particular drained peatland complex. Further, the changes occuring in peat after regulation of soil water have surely affected the nutrient balance of the site.

Even if the active rooting zone after drainage does not absolutely seen extend much deeper than prior to water regulation (HEIKURAINEN 1955, PAAVILAINEN 1968), lowering of the ground water table imply anyway that the uptake of nutrients can occure more intensively. Of much greater importance for the nutrient budget than the small increase in root penetration depth is the considerable change in the peat mass of the rooting zone. Forest drainage directly influences the bulk density of the organic soil through an increased turnover rate. In addition, a vigorously growing tree stand exerts an ever increasing mechanical pressure on the spongy substrate. As the bulk density already in natural conditions increases with increasing peat depth (cf. ISOTALO 1951), even a small change in the depth of the rooting zone may give a much greater improvement in the nutrient balance than indicated by the volumetric change as such. This process is of particular importance as primarily the contents of, in the first place, nitrogen and phosphorus increase with increasing bulk density (ch. 31.6–7). Secondly, the absolute amount of nutrients in peat is strongly dependent on the bulk density.

The increased peat mass in the rooting zone after drainage is thus a satisfactory explanation for the good timber production obtained on the sites in question. Consequently, there is every reason to strongly emphasize the importance of the bulk density of peat when evaluating the nutrient balance of a site. Estimating the quality of a site on the basis of nutrient contents (mg/g) only can result in a considerable error. Further, it must be stressed that the average absolute amounts (figure 28) were calculated after transformation of the nutrient data. Owing to this, the effect of high individual observations was to some extent eliminated.

The importance of calcium in soil has possibly been to some extent overestimated in forestry when applying experiences obtained in agriculture. The element has gained importance primarily with regard to its general influence on soil properties rather than as a nutrient. This emphasis is important, however, when examining acid peat soils, where the microbiological nutrient mineralization is highly dependent on soil acidity. The absolute amount of calcium calculated for the 20 cm deep peat layer varies between 197 kg/ha and 764 kg/ha (Figure 28), most of it being fairly easily available to plants (STARR & WESTMAN 1978). Compared with calcium uptake in middle-aged pine stands (MÄLKÖNEN 1974), one can state that the amounts found are satisfactory. KAILA and KIVEKÄS (1956) report somewhat higher amounts. The reason for this difference is, however, found in the calculation method where artificial bulk density was used.

In principle, magnesium influences the substrate in the same way as calcium, as it is also a basic cation, but the amount of magnesium in soil is considerably smaller than that of calcium. It is thus likely that the supply for uptake by plants is of greater importance than its general effect on soil processes (cf. KIVEKÄS & KAILA 1957). Some 60–70 per cent of the total magnesium in peat is easily available to plants (STARR & WESTMAN 1978). The absolute amount of magnesium calculated for the 20 cm deep peat layer varies between 52 and 149 kg/ha, which approximately corresponds to data reported by KAILA and KIVEKÄS (1956) for the surface layer from virgin peatlands.

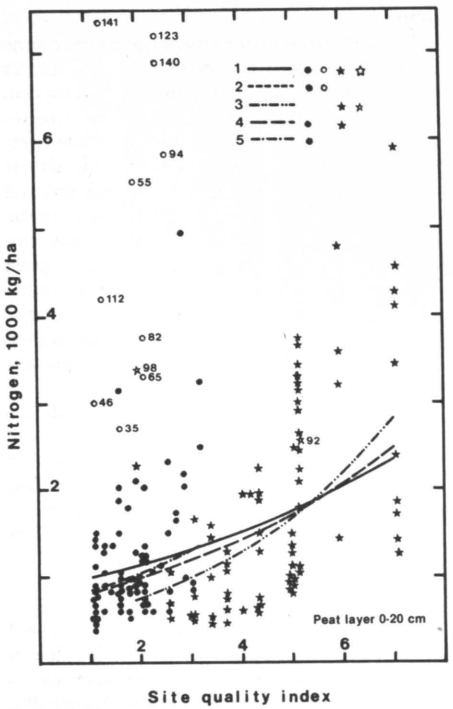

Figure 29. Scatter diagram showing the relationship between site quality index and the absolute amount of nitrogen in the 20 cm deep surface peat layer. For the mathematical models see Table 31.
1 = All sample plots
2 = Sample plots with annual accumulative temperature ≤ 1050 dd
3 = Sample plots with annual accumulative temperature > 1050 dd
4 = Sample plots remaining when extremes are excluded
5 = Sample plots with annual accumulative temperature ≤ 1050 dd, extremes are excluded.
Data from the extreme sample plots are marked with open symbols, the corresponding bulk densities are given in g/dm^3.

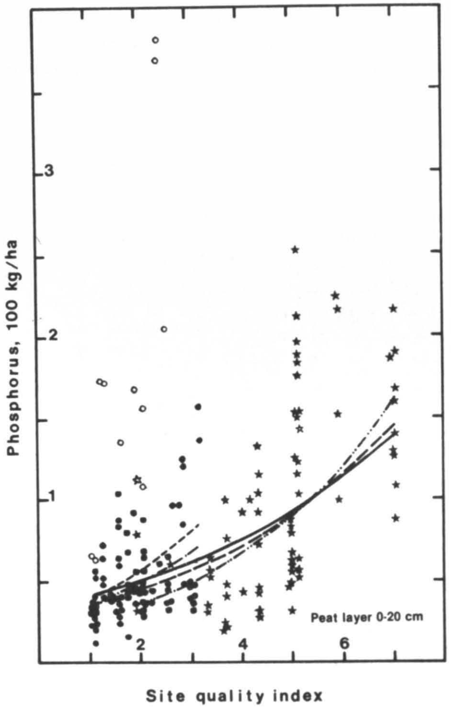

Figure 30. Scatter diagram showing the relationship between site quality index and the absolute amount of phosphorus in the 20 cm deep surface peat layer. For the mathematical models see Table 31, symbols legend is given in Figure 29.

Compared with the amount of 1.1 kg/ha magnesium given by BRINGMARK (1977) for annual above ground net uptake in an old pine stand on poor mineral soil, the magnesium content in peat from the site series studied seems to be satisfactory.

33.2 Prediction of site quality index on the basis of soil fertility data

As seen in chapter 33.1, the supply of nitrogen, phosphorus and potassium in peat from, in particularly, the two less fertile site types may be factors limiting stand development after drainage. Neither does peat from the herb-rich sedge mires show more than adequate amounts of the nutrients; with regard to the nutrient supply the site type series is at the least fertile end of the site amplitude of pine. This certainly facilitates setting up an overall model for the relationship between the nutrient economy of soil and the timber production potential. Site quality index (HEIKURAINEN 1973a, ch. 12, 23) is used as a measure for timber production potential.

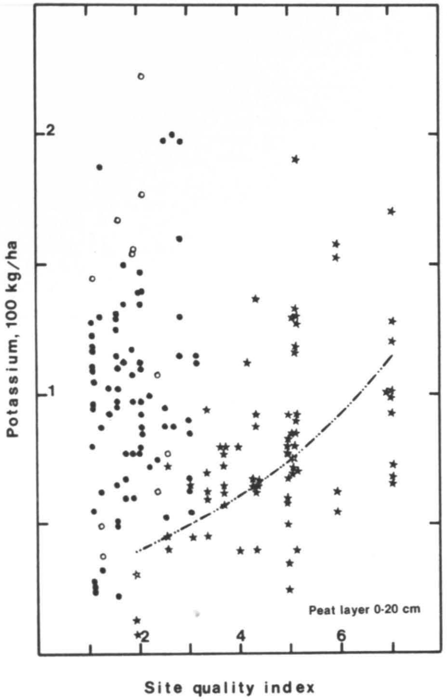

Figure 31. Scatter diagram showing the relationship between site quality index and the absolute amount of potassium in the 20 cm deep surface peat layer. For the mathematical models see Table 31, symbols legend is given in Figure 29.

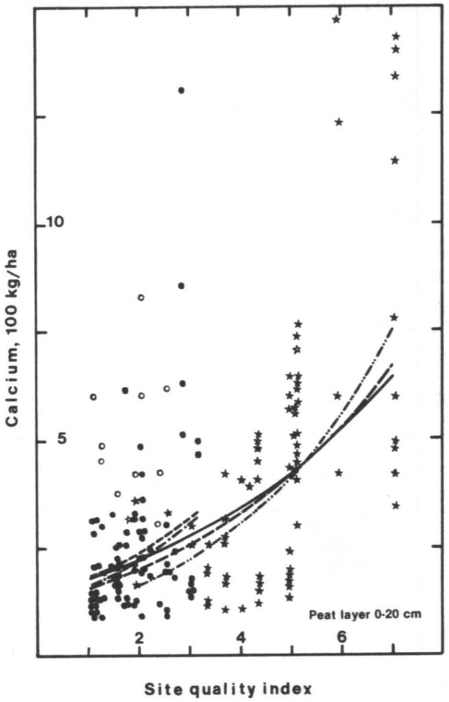

Figure 32. Scatter diagram showing the relationship between site quality index and the absolute amount of calcium in the 20 cm deep surface peat layer. For the mathematical models see Table 31, symbols legend is given in Figure 29.

The relationships between the site quality index (X) and the absolute amounts of the macronutrients in the topmost 20 cm deep peat layer (Y) are illustrated in Figures 29–33. Despite considerable variation the scatter diagrams indicate correlations between the site quality index and the absolute amounts of nitrogen, phosphorus, calcium and magnesium. Correlation coefficients using the logarithmically transformed absolute amounts can be seen in Table 30. It is interesting that a strong correlation is obtained with phosphorus, while that with nitrogen and potassium, which were expected to be of similar importance for site quality, are no higher than 0.36 and 0.02 respectively. On the other hand the calcium and magnesium contents, which were assumed to affect stand development indirectly, show remarkably strong correlations.

The variation of the absolute amount of nitrogen, and to some extent also the phosphorus amount, show certain features affecting the correlations. It appears from the scatter diagram in Figure 29 that the absolute amount of nitrogen in the site quality index interval 1.0–2.5 show an extremely skewed distribution. It even seems as if the observations within the interval would represent two different populations. A closer examination reveals that these high individual nitrogen amounts in most cases correspond to sample plots situated in north Finland (annual accumulative temperature ≤ 1 050 dd.). The plots are distributed between the three site types in approximately the same way as the entire material, the proportions from the least to the most fertile site type

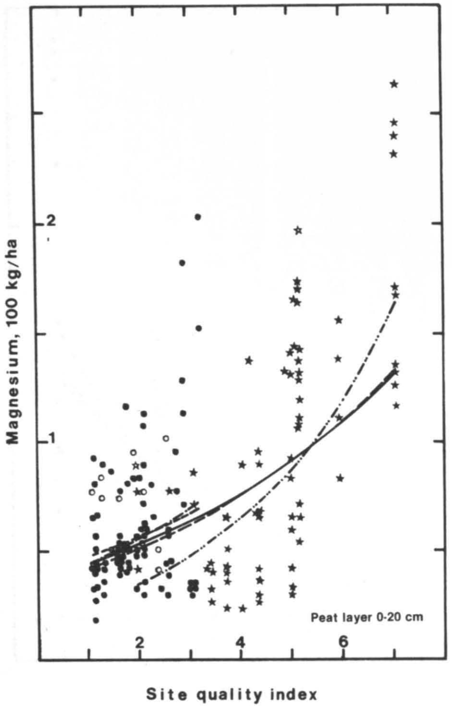

Figure 33. Scatter diagram showing the relationship between site quality index and the absolute amount of magnesium in the 20 cm deep surface peat layer. For the mathematical models see Table 31, symbols legend is given in Figure 29.

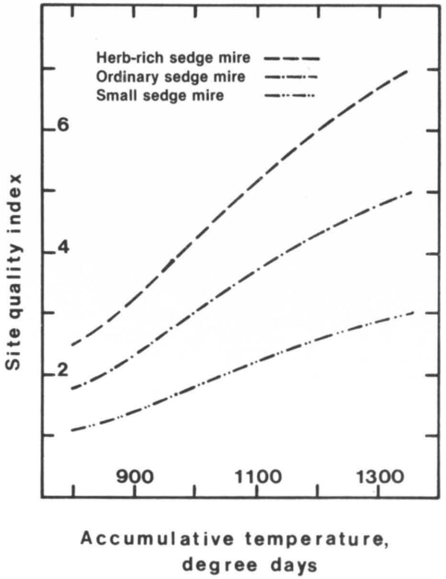

Figure 34. The relationship between site quality index (Heikurainen 1973a) and annual accumulative temperature.

being 33, 58 and 8 per cent and 26, 64 and 16 per cent, respectively. These series indicate that the proportion of small sedge mires amongst the extreme sample plots would even be somewhat higher at the expense of the most fertile sites.

When examining all the site variables registered, one finds common denominators for the sample plots with extreme amounts of nitrogen. On one hand, bulk density tends to be relatively high (cf. Figure 29) and, on the other hand, there is a considerable proportion of *Sphagnum cuspidatum* in the ground vegetation bottom layer. The high bulk density has surely contributed to the extreme nitrogen and phosphorus figures as the contents of the two nutrients show clear positive dependence on the bulk density (Tables 4 and 18 Figure 11). This effect is further strengthened in transforming the contents into absolute amounts. No causal reason for the high bulk densities can, however, be given. The occurence of *Sphagnum cuspidatum* is somewhat controversial as this moss dominates in extremely wet parts of the mire plane and often forms relatively noncompact populations (cf. NYHOLM 1969). It cannot be excluded either that the high nitrogen contents are results of autotrophic nitrogen fixation, although the white moss species *Sphagnum cuspidatum* as such does not indicate this (KALLIO & KALLIO 1975, BASILIER 1979).

In the following, calculations will be made both for the entire material and after exclusion of the 12 sample plots subjectively classified as extreme cases (cf. Figures 29–33, Table 30). As expected, these plots have strongly influenced the relationships between the site quality index and the two organically bound nutrients: nitrogen and phosphorus, the latter nutrient now being more strongly correlated with the site quality index than calcium (Table 30). Little change takes place in the case of the other elements. The coefficients for the individual regressions for the entire climatic region as well as separetely for the two climatic regions (≤ 1 050 dd. >) are presented in Table 31.

The division into two climatic regions is motivated by the site dependent relationship between site quality index and macroclimate (Figure 34). Thus, for example, the herb-rich sedge mires under severe climatic conditions, despite a favourable nutrient economy, obtain the same site quality indices as the least fertile site type does in south Finland. (cf. HEIKURAINEN 1973a).

Except for potassium, which shows no correlation, the degrees of explanation for the entire material vary between 10 and 30 per cent. The best results are obtained with calcium and magnesium. In models for the northern climatic region (≤ 1 050 dd.) lower degrees of explanation are generally obtained and in the case of nitrogen there is no correlation. On the other hand, in the southern climatic region (>1 050 dd.) the degrees of explanation rise to between 30 and 40 per cent. The strongest correlation in this region is obtained with magnesium. There is also a clear positive dependence ($R^2 = 0.291$)

Table 30. Simple correlations between the site quality index and the logarithmically transformed absolute amounts of macronutrients.

Correlations in the entire material / Corre-lations in the reduced material	Site quality index	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
	Entire climatic region					
						n=160
Site quality index	–	0.36	0.51	0.02	0.56	0.54
Nitrogen	0.53	–	0.90	0.21	0.78	0.67
Phosphorus	0.65	0.90	–	0.21	0.75	0.66
Potassium	0.03	0.24	0.24	–	0.25	0.29
Calcium	0.63	0.81	0.77	0.24	–	0.87
Magnesium	0.57	0.76	0.73	0.33	0.89	–
	n=148					
	Northern climatic region (≤1050 dd)					n=87
Site quality index	–	0.19	0.34	0.19	0.30	0.25
Nitrogen	0.29	–	0.90	0.21	0.71	0.52
Phosphorus	0.44	0.82	–	0.19	0.63	0.46
Potassium	0.20	0.32	0.28	–	0.40	0.42
Calcium	0.37	0.66	0.57	0.43	–	0.81
Magnesium	0.30	0.61	0.54	0.47	0.86	–
	n=77					
	Southern climatic region (>1050 dd)					
						n=73
Site quality index	–	0.53	0.60	0.54	0.62	0.64
Nitrogen	0.59	–	0.91	0.32	0.86	0.80
Phosphorus	0.64	0.91	–	0.44	0.81	0.77
Potassium	0.52	0.36	0.46	–	0.35	0.40
Calcium	0.63	0.87	0.81	0.35	–	0.89
Magnesium	0.67	0.81	0.77	0.42	0.89	–
	n=71					

Table 31. The regression models for the relationship between the site quality index (X) and absolute amounts of the indiviadual macronutrients (Y).

Dependent variable and climatic region[1])		Regression				Analysis of variance	
		Constant	Regr.coeff.	T-value	R^2	d.f.	F-value
		Entire material					
ln N	E	6.757	0.142	4.81***	0.128	1,158	23.12***
ln N	S	6.106	0.262	5.26***	0.281	1,71	27.72***
ln P	E	3.544	0.199	7.40***	0.258	1,158	54.83***
ln P	N	3.325	0.352	3.33***	0.115	1,85	11.08**
ln P	S	2.986	0.299	6.40***	0.366	1,71	40.96***
ln K	S	3.286	0.210	5.40***	0.291	1,71	29.15***
ln Ca	E	4.973	0.214	8.40***	0.309	1,158	70.63***
ln Ca	N	4.905	0.282	2.88**	0.089	1,85	8.31**
ln Ca	S	4.437	0.313	6.67***	0.385	1,71	44.48***
ln Mg	E	3.635	0.179	8.10***	0.293	1,158	65.55***
ln Mg	N	3.690	0.184	2.41**	0.064	1,85	5.81*
ln Mg	S	2.959	0.303	6.98***	0.407	1,71	48.78***
		Reduced material					
ln N	E	6.502	0.188	7.61***	0.284	1,146	57.93***
ln N	N	6.483	0.231	2.59**	0.082	1,75	6.73*
ln N	S	5.922	0.295	6.03***	0.345	1,69	36.39***
ln P	E	3.335	0.235	10.24***	0.418	1,146	104.87***
ln P	N	3.196	0.341	4.27***	0.195	1,75	18.21***
ln P	S	2.846	0.324	6.91***	0.409	1,69	47.78***
ln K	S	3.324	0.202	5.00***	0.266	1,69	25.04***
ln Ca	E	4.827	0.240	9.76***	0.395	1,146	95.18***
ln Ca	N	4.731	0.321	3.50***	0.140	1,75	12.26***
ln Ca	S	4.353	0.327	6.80***	0.402	1,69	46.29***
ln Mg	E	3.574	0.189	8.32***	0.321	1,146	69.17***
ln Mg	N	3.590	0.222	2.74**	0.091	1,75	7.52**
ln Mg	S	2.841	0.325	7.46***	0.447	1,69	55.71***

[1]) E=entire climatic region, N=northern climatic region (1050 dd), S=southern climatic region (1050 dd).

between potassium and the quality index. It is a matter of course that the explanation power of especially the models for the entire climatic region increases when extreme sample plots are excluded.

An interesting feature with the models set up is that they explains upto 30–40 per cent of the relationships between the site quality index, which is an average index for potential productivity, and individual fertility factors. However, the regression coefficients obtained are not only indications of the direct correlation between the growth potential and the individual nutrient level, but also reflect the effects of other variables not included in the models. Since there prevails strong correlations between the various nutrients (Tables 4, 31) this implies that, in the first place, several nutrients influence the regression coefficient in each individual nutrient model (cf. SNEDECOR & COCHRAN 1968). This multiplicative effect is best described by a multiple regression model:

$$Y = a_1X_1 + a_2X_2 \ldots + a_nX_n + C$$

Nearly 50 per cent of the variations in the site quality index can be explained in a multiple regression model using the nutrient data. (Table 32, model 1). If the annual accumulative temperature is also included as another independent variable, the degree of explanation is increased to above 85 per cent (Table 32, model 2). In the latter model magnesium, was not taken as an independent variable, but the regression is highly influenced by the calcium economy. As this element and magnesium are strongly correlated (cf. ch. 31.9, Table 30), it is likely that the effect of magnesium is included in the regression coefficient for calcium.

Table 32. The multiple regression models for the relationship between the site quality index (Y) and the logarithmically transformed absolute amounts of macronutrients (X). In the overall models annual accumulative temperature is used as an additional independent variable.

Independent variables	Regression				Analysis of variance	
	Constant	Regr.coeff.	T-value	R^2	d.f.	F-value
	Entire material model 1					
ln N	2.720	−2.135	5.91***	0.481	5,154	28.54***
ln P		2.101	6.06***			
ln K		−0.529	2.57*			
ln Ca		1.144	3.19***			
ln Mg		0.699	1.96*			
	model 2					
ln N	−7.880	−0.575	2.78**	0.854	5,154	180.31***
ln P		0.616	3.10***			
ln K		0.336	2.93**			
ln Ca		0.620	4.42***			
ln Mg		–	–			
accum. temp.		7.21x10^{-3}	20.18***			
	Reduced material model 3					
ln N	−0.246	−1.374	3.44***	0.520	4,143	38.79***
ln P		2.016	5.70***			
ln K		−0.503	2.40*			
ln Ca		1.290	4.88***			
ln Mg		–	–			
	model 4					
ln N	−10.064	–	–	0.859	5,142	172.31***
ln P		0.360	2.51*			
ln K		0.391	3.07***			
ln Ca		0.793	4.03***			
ln Mg		−0.497	2.28*			
accum. temp.		7.25x10^{-3}	19.46***			

Calculating the overall regressions after excluding the sample plots showing extreme peat properties, reveals that the models are to no notable degree affected. Taking only the absolute amount of nutrients as independent variables increases the degree of explanation by approximately 4 percentage units (Table 32, model 3). In the model including the annual accumulative temperature the same degree of explanation is obtained as in the model with the entire material, i.e. 85 per cent (Table 32, model 4).

In the two models with the reduced material, magnesium has been excluded in the former case, while using the annual accumulative temperature as an independent variable has resulted in an increased importance of magnesium. Of greater interest is that multicolinearity between the nutrients and the temperature climate in the last model (4) eliminates the effect of the nitrogen factor, a trend also to be seen in the models with the entire material.

The influence of nitrogen in the models is in general unexpected. The regression coefficients are throughout negative, although the correlation between nitrogen amount and site quality index is clearly positive (Figure 29, Table 30). Explanation for this discrepancy must be sought in the complicated relationships between the nutrients. When the multiple regression is gradually built up on the basis of the partial correlations between the dependent and not yet included independent variables, an individual positive correlation can become a negative in the regression model. This occurs with the correlation between nitrogen and the site quality index when, besides the effect of the accumulative temperature, those of phosphorus and calcium are eliminated. The coefficient for the simple correlation then changes from 0.37*** to – 0.25***. These correlations also give a plausible explanation for there being no tangible differences between the models set up for the entire as well as the reduced materials. The high nitrogen amounts characterizing the extreme sample plots have certainly contributed to the negative partial correlations.

Owing to the correlation between the independent variables one cannot, although the models in Table 32 give high degrees of explanation, draw any conclusions regarding the relative importance of the individual variables. However, if one calculates on the basis of the simple correlations (Table 30) the partial correlations with the site quality index the importence of individual nutrients is seen. By eliminating the effect of one or several variables a theoretically pure correlation between any individual variable and the site quality index is obtained. As the accumulative temperature primarily determines the site quality index as well as affects the content of certain nutrients and the bulk density of peat (ch. 32.2), its effect on the simple correlations will be examined first. It appears that the correlation between potassium amount and site quality index is affected the most; after elimination of the temperature climate a significant positive correlation is obtained (Tables 30, 33). The correlations between the other nutrients and the site quality index are not altered to any high degree and the strongest correlation is still obtained with calcium.

Table 33. Partial correlations between the site quality index and the logarithmically transformed absolute amounts of macronutrients.

Correlated variable	Partial correlations with site quality index after elimination of:						Partial correlations after elimination of all variables	Nutrients with strongest effect on the simple correlation
	accum. temp.	accum. temp. + N	accum. temp. + P	accum. temp. + K	accum. temp. + Ca	accum. temp. + Mg		
	Entire material				n=160			
ln N	0.37	–	0.07	0.30	–0.04	0.15	–0.22	P, Ca
ln P	0.44	0.27	–	0.37	0.13	0.27	0.24	N
ln K	0.39	0.33	0.30	–	0.26	0.27	0.25	P, Ca
ln Ca	0.51	0.38	0.31	0.43	–	0.33	0.32	N
ln Mg	0.41	0.24	0.20	0.29	–0.04	–	–0.10	N, K, Ca
	Reduced material				n=148			
ln N	0.45	–	0.01	0.38	0.06	0.23	–0.13	P, Ca
ln P	0.51	0.28	–	0.44	0.22	0.34	0.24	N
ln K	0.38	0.27	0.24	–	0.24	0.23	0.24	P, Ca
ln Ca	0.55	0.34	0.30	0.47	–	0.37	0.34	N
ln Mg	0.43	0.18	0.15	0.32	–0.08	–	–0.18	N, K, Ca

When eliminating in addition to accumulative temperature, the individual nutrients one by one in proper order, calcium and potassium in each case give the strongest partial correlations (Table 33). This holds also for the partial correlations where, besides annual accumulative temperature, the effect of four nutrients on the correlation of the remaining element is eliminated. Further, on the basis of these calculations, the positive relationship between the nitrogen amount and site quality index (Table 30) is explained by multicolinearity with phosphorus and calcium. Excluding the effect of the two elements results in the previously mentioned negative partial correlation of nitrogen. In this connection can be stressed that the strong correlations between on one hand nitrogen and phosphorus and on the other hand between nitrogen and calcium give rise to an apparent correlation between phosphorus and calcium.

To conclude, it seems that nitrogen, phosphorus and calcium used individually or in combinations affect mostly the simple correlations given in Table 30. Only the relationship between absolute amount of magnesium and site quality index is to some extent affected also by correlation with the amount of potassium in peat. The importance of calcium and potassium in explaining the site quality index as well as the dominance of the phosphorus amount over the nitrogen amount (Table 33) is in accordance with the established opinion of the nutrient balance in peat. Of the two former elements, calcium is primarily connected to the trophy concept of the site series investigated. Potassium and phosphorus are traditionally considered the most growth limiting macronutrients on drained peatland sites (LUKKALA & KOTILAINEN 1951, HUIKARI & PAAVILAINEN 1972, HEIKURAINEN 1973b).

4 Concluding remarks

This investigation is based on the assumption that the the timber production potential of sites within a uniform climatic region is determined by the water and nutrient supply in the soil. By eliminating the variation of one of the factors, it is possible to examine the other. The assumption clearly simplifies the complex interaction between the site factors and the corresponding vegetation association, an interaction difficult to examine on the basis of any individual factor (cf. DICKSON 1962, HOLMEN 1964). By limiting a study to a defined section of a vegetation continuum one can, however, state that hydrology and nutrient supply in soil are the most important factors in determining the site quality. Whether one then, by relating the composition of the surface vegetation to the physical and chemical properties of soil, can draw conclusions about the timber production potential, is debatable.

Productivity studies (e.g. HEIKURAINEN 1959, ILVESSALO 1965) and a vast experience in practice have indeed given a satisfactory picture of postdrainage stand development on different site types (CAJANDER 1909, 1913), but the move towards an understanding of the relationship between direct measured soil properties and productivity is difficult. Initially there are difficulties in obtaining a representative sample and in choosing the right methods for determination of soil properties as well as in expressing the analytical results in a meaningful way. The first mentioned difficulties are particularly experienced on mineral soils. There nutrients are derived from minerals and the plant available fractions and the rate of mineralization are difficult to define. Further, the soil type formation gives rise to several pronounced horizons in the rooting zone to be sampled.

In peat soils, where the nutrients are either bound in organic forms or absorbed in the ion exchange complex, it is relatively simple to measure the nutrient economy. In this case, total nutrient contents can be determined using the same methods as for plant material, which are relatively straightforward, simple and quick. As a peat deposit as such is a soil type horizon no restrictions on sampling arises from this point of view. Decisions about sampling depth is mere a question of defining the layer of importance for the nutrient economy of the site. In this study, the topmost 20 cm layer has been taken, which is frequently used in peatland forestry (e.g. HOLMEN 1969 PAARLAHTI el al. 1971). It is, however, probable that sampling from a deeper peat layer would better describe the quality of peatland sites. Finally, peat soils due to the nature of the peat forming process probably are more homogeneous than mineral soils.

The aim of the investigation was to examine the relationship between the properties of surface peat and the ground vegetation of the sedge mires: a site series which was assumed to meet the criteria given. Sample material was collected from virgin sites all over Finland, the validity of which with regard to statistical testing will be discussed in the following.

The sampling was performed by checking selected peatland areas. In north Finland, peatlands were selected on the basis of a map survey of regions known to be rich in peatlands and, in the central and south part of the country, by choosing peatland preservation areas and peatlands that were to be shortly drained. All sedge mires found were accepted providing that they could be considered virgin. Thus, although the peatland areas were subjectively chosen sampling within each area was random. Therefore, statistical testing is valid and inference possible. It should, however, be noted that the analysis of variance used (KORHONEN 1978) in examining the site type dependence of the soil properties, does not strictly allow general conclusions to be made.

By limiting the investigation to a few site types close to each other in hydrological respect, it was assumed that the variations in the physical properties of peat could be restricted and made uniform within the site series. A closer examination reveals that the condition is not fully satisfied and that a certain site type dependence among the physical properties exists. The bulk density of peat as well as the degree of decomposition tend to increase somewhat from the two less fertile to the most fertile site types. The same is also true of the ash content of peat, which on the other hand can equally be allocated to the chemical properties, as it is a rough overall value for the content of mineral nutrients in peat. The significance of diffrences in bulk density and degree of decomposition are limited to the herb-rich sites. Whether the post-drainage stand development from a hydrological point of view is influenced cannot be decided, but the tendency towards increased bulk density is important when transforming the nutrient concentration contents of peat into absolute amounts per square unit.

In examining the chemical properties of peat after classification according to site type, a clear positive relationship is obtained with the degree of acidity as well as with the electric conductivity.

The cation exchange capacity does not show any logical site dependent variations. Since the electric conductivity and, even more so, the pH are overall site factors like the ash content, the gradients found must be considered indicative of the site type – nutrient relationships to be discussed below. Absence of a relationship between site type and effective cation exchange capacity is understandable against the high exchange capacity of the organic matter. On the other hand, correlations between cation exchange capacity, potassium content and bulk density suggests that the exchange capacity is limiting for the potassium economy in peat from the most fertile site type. As peat from these sites is relatively rich in calcium and magnesium antagonism between these elements and potassium in the exchange complex is, however, a more probable explanation for this somewhat surprising finding. In accordance with this, the degree of base saturation, which is strongly correlated with the content of calcium and magnesium in peat, shows a clearly positive relationship with the site quality gradient.

The relationship between the content of macronutrients in peat and the site quality gradient is surprisingly clear. Differences between the site types are in the most cases statistically significant. If the nutrient status is expressed as concentration data, i.e. mg nutrient per gram, clear increases in mean contents from the least to the most fertile site type are obtained, excepting for potassium. Converting on the basis of the bulk density of peat the nutrient contents into absolute amounts, i.e. kg nutrient per square unit, results in a positive relationship even between potassium and site quality. The trends shown by potassium and magnesium are interesting as the site quality has generally been considered indifferently or even negatively related to these nutrients (WARÉN 1924, BRENNER 1930, HEIKURAINEN 1953, VAHTERA 1955, HOLMEN 1964). The influence of the bulk density on the site fertility can also be seen in the sampling depth dependent changes in the contents and absolute amounts of nutrients respectively. The change is considerably stronger for the absolute amounts and strongly emphasizes the necessity for expressing site fertility on the basis of absolute figures. Using the more easily available concentration data may result in a severe underestimation of site quality. The nutrient uptake process may also be related to a deeper peat layer than sampled.

To summarize, one can say that within the sedge mires the absolute amounts of macronutrients follow the accepted quality gradient of the site type series (LUKKALA & KOTILAINEN 1951, HEIKURAINEN 1959, HEIKURAINEN & HUIKARI 1960). This conclusion indicates that the plant sociologically based Cajanderian site classification reflects satisfactorily the average soil properties that determine plant growth. Whether one then is able on the basis of soil chemical analyses to construct a site classification applicable in practice is questionable. The relationships shown are based on mean values calculated for the various site types. The distribution within the classes is in all cases considerable. Placing an individual site at its appropriate point in a series of sites is thus, understandably difficult. The question then remains, what possibilities are there to include this within the class variation.

Although no clear influence of microtopography (hummock/mire plane) could be shown, one can assume that a careful definition of the sampling procedure can reduce the within site type variation of soil data. Another external factor of interest is the macroclimate. By correlating the soil variables to the annual accumulative temperature, indications for its influence were obtained. The regressions were in several cases non-linear showing a minimum in the interval 1 000–1 200 degree days. This inflexion point, which is most clearly seen for the pH and magnesium content, can not be explained directly by variations in the macroclimate. Probable reasons may be variations in the biological activity in soil at the time of sampling. It could not be excluded either that the magnesium balance is influenced by the underlying mineral soil.

Linear or almost linear regressions with the annual accumulative temperature were obtained with the effective cation exchange capacity and content of potassium, each of which were clearly negatively correlated to the macroclimate. This can scarcley be taken as definite evidence that plant communities under more severe climatic conditions require a higher potassium content in soil but must, at least, partly be attributed to multicolinearity between the three variables. Primarily, the humus synthesis is affected by variations in the macroclimate, which can be seen as variations in the cation exchange capacity. A possibility of contamination with mineral soil cannot be excluded in the case of the highly mobile potassium ion. The limitations applied in the sampling process, however, aimed at eliminating this risk. As the depth of the peat deposits in all cases exceeded 1.5 m and as the other nutrient cations do not show any comparable clear trends, contamination does not seem probable.

The above mentioned factors affecting variable distribution only correspond to a small part of the total variation within the classes. A considerably more perceptible factor is the heterogeneity of the plant communities studied. When laying out the sample plots on the peatland areas accepted for sampling the site type as a whole was determined. No attention was paid to differences in the vegetation cover from one sampling point to another. Thus, the composition of the surface vegetation varies considerably within each site type class. A much more homogeneous result would probably be obtained if the material were ordinated on the basis of the surface vegetation of the individual sampling point. However, this falls outside the scope of the present investigation.

The absolute amounts of nutrients in the 20 cm deep surface peat layer from the site series are, with the exception of magnesium and possibly calcium, small. When comparing the amounts of nitrogen, phosphorus and potassium with data given by HOLMEN (1969) as minimum requirements for continuous timber production on drained peatlands, only the herb-rich sites show a somewhat satisfactory nutrient economy. Productivity studies and extensive practical experience (HEIKURAINEN 1959, 1972, 1973b) have shown that drainage on ordinary sedge pine mires and even on small sedge pine mires gives an acceptable timber production. Thus, it seems as if the values presented by HOLMEN (1969), which refer to an individual peatland complex, have been taken at the upper limit or, what is more important, that the tree stand after drainage is able to take up nutrients from a peat layer deeper than 20 cm. The latter assumption is connected to the post drainage fluctuations in the bulk density of the peat. As was noted, an increase in bulk density exerts a positive influence on the absolute amount of nutrients in peat. This involves that a minor increase in the volume of the rooting zone in particular after drainage results in a relatively greater improvement in the nutrient balance.

Models set up for the relationship between the absolute amount of individual nutrients in soil and site quality index as well as overall multivariate models with soil fertility data and annual accumulative temperature as independent variables, results in high degrees of explanation. It is remarkable that, by using the absolute amounts of macronutrients and the macroclimate, one is able to determine with reasonable precision the site quality index. It seems as if the considerable within class variation, common for all the site factors, is highly reduced in the multiple regression models. Formulas calculated with the material in its entirety as well as after exclusion of a number of sample plots subjectively judged as extremes with regard to nutrient economy, does not differ to any higher degree. However, whether the models derived from the data collected in this study can be used to estimate the site quality index from other data sources is disputable.

It must be emphasized that the site quality index (HEIKURAINEN 1973a) used to ordinate the sedge mires is an average index for potential post-drainage growth based on relative increment values. The intricate question then is, if a multivariate model using nutrient data and annual accumulative temperatur, better describes post-drainage stand growth than the site quality index. No final answer can be given here as empiric testing of the models fromed is a very troublesome experiment. However, the multivariate regression models do offer a possibility to calculate a quality index based on soil fertility data obtained for individual sites. This must certainly be seen as move towards a more precise site classification.

5 SUMMARY

Fertility of surface peat from sedge pine[1] mires was studied by measuring the following edaphic growth factors: bulk density, volume weight of organic matter, ash content, acidity, electric conductivity, effective cation exchange capacity, degree of base saturation as well as total contents of nitrogen, phosphorus, potassium, calcium and magnesium. The research material consists of 168 temporary sample plots on virgin sedge mires from all over Finland. An additional 30 sample plots were included, selected randomly from amongst 200 permanent plots on two uniform sedge mires.

In general, the data obtained for the various site factors ranges within limits given for *Sphagnum* and *Carex* peat or peat from comparable sites. Only the total content of potassium in the peat samples is higher than data reported for drained pine mires. This may be taken as an indication of biological fixation of potassium after regulation of the soil water level or leaching losses.

Grouping the soil data according to site type (herb-rich, ordinary, and small sedge mires) and sampling layer (0–10 cm and 10–20 cm) reveals that among the physical properties of peat bulk density and volume weight of organic matter as well as ash content tend to increase with increasing site quality. In the case of the two former factors the differences appear between the most fertile site type and the two others. The ash content, which is considered a guide to site quality, increases gradually in the site series from the small sedge mire to the herb-rich sedge mire. It can be added that volume weight of organic matter and, what may be of particular importance when evaluating site quality, bulk density increases from the upper to the lower peat layer.

Owing to the good exchange properties of organic matter the effective cation exchange capacity is high in the peat samples from all the three site types. In the lower sampling layer the exchange capacity significantly decreases from the two less fertile site types to the most fertile type. This trend is, however, explained by correlation with bulk density. Although the exchange capacity is uniform within the sedge mire series the degree of base saturation clearly increases with increasing site quality. In peat from the most fertile site type there even prevails a significant positive correlation between effective cation exchange capacity and degree of base saturation. The electric conductivity and pH of peat, which are additional overall variables, also follows the established site quality gradient of the site series.

The relationship between the total content of macronutrients in peat and the site quality gradient is surprisingly clear. Differences between the site types are in most cases statistically significant. If the nutrient status is expressed as concentration data (mg/g), excepting for potassium, clear increases in mean contents from the least to the most fertile site type are obtained. The unfavourable potassium economy of peat from the herb-rich sedge mires is probably due to correlations between potassium, effective cation exchange capacity and bulk density, and antagonism between the basic cations.

Transforming on the basis of bulk density of samples the nutrient contents into absolute amounts (kg/ha) results in a positive relationship even between potassium and site quality. The influence of the bulk density on the site fertility can also be seen as sampling depth dependent changes in the contents and absolute amounts of nutrients respectively. The importance of bulk density in evaluating the site quality is further emphasized when taking into account its significant correlation to contents of nitrogen and phosphorus.

To summarize, one can say that within the sedge mires the soil variables, with particular stress on the absolute amounts of macronutrients, follow the accepted quality gradient of the site series. The conclusion indicates that the plant sociologically based Cajanderian site classification reflects satisfactorily the average soil properties. The within site variation is, however, most considerable.

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[1] See page 7.

An attempt to explain the within class variation on the basis of external site factors revealed that there exist no significant difference between samples extracted from hummock and mire plane[1], respectively. On the other hand, significant relationships between macroclimate and certain soil properties were shown. The relationship is negative in the case of effective cation exchange capacity and total content of potassium. The bulk density probably increases somewhat with increasing annual accumulative temperature while the pH and total content of magnesium show more or less pronounced inflexion points in the degree days interval 1 000–1 200. Any definite connection between site quality and lithology of underlying material could not be shown. Neither did further classification of the material alter the relationships between soil properties and site type.

The absolute amounts of macronutrients in peat were calculated on the basis of the concentration content data and corresponding sample bulk density. In comparison with minimum requirements given for continuous timber production on drained peatlands, the amounts found are low. Only the herb-rich sedge mires show in virgin conditions a fairly sufficient nutrient economy. Satisfactory results of forest drainage on sedge mires were explained by changes in the peat mass and volume of the rooting zone taking place along with accelerating post drainage stand growth.

An attempt to produce an overall expression for the relationship between soil fertility and site quality was made. Firstly, the connection between a site quality index and the individual macronutrients were established by means of regression analysis. Degrees of explanation up to 40 per cent were obtained. Finally the site quality index applied was used as a dependent variable in multivariate regression models where the absolute amounts of macronutrients in the 20 cm deep surface peat layer and the annual accumulative temperature were used as independent variables. Explanation degrees of 85 per cent give indications of possibilities to forecast post drainage timber production on the basis of soil data from virgin sites.

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[1] See page 7.

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SELOSTE

PINTATURPEEN VILJAVUUSTUNNUKSET SUHTEESSA KASVUPAIKKATYYPPIIN JA PUUSTON KASVUPOTENTIAALIIN

Tämän tutkimuksen tavoite on lisätä tietoa Cajanderin kasvupaikkatyyppien avulla ilmaistun puuston kasvupotentiaalin ja pintamaan ravinteisuuden välisestä riippuvuudesta. Tutkimuksessa oletetaan että puuston kasvu tietyssä ilmastovyöhykkeessä määräytyy pääasiallisesti maan vesitalouden ja ravinteisuuden mukaan, ja eliminoimalla toisen tekijän vaikutus voidaan tarkastella toisen tekijän vaihtelua. Tarkastelun kohteeksi valittiin turvemaiden kasvupaikkatyyppisarja: ruohoinen sararäme, varsinainen sararäme ja lyhytkortinen räme. Sararämeiden kohdalla voidaan olettaa, että erot ojituksen jälkeen elpyneen puuston kasvussa määräytyvät pintaturpeen ravinteisuuden perusteella. Sarjan vähiten viljavat kasvupaikat, lyhytkortiset rämeet, sijoittuvatkin männyn luontaisen kasvupaikka-amplituudin äärirajan tuntumaan, mikä helpottaa maan viljavuustunnusten ja kasvun välisten riippuvuuksien toteamista. Lisäksi sekä maanäytteiden otto että niiden analysoiminen laboratoriossa on yksinkertaisempaa maannoksen ollessa turvetta kuin sen ollessa esim. podsoloitunutta kivennäismaata.

Aineisto käsittää 198 kertakoealaa 51 eri suoalueella ympäri Suomea (kuva 1). Koealoilta määritettiin Cajanderin suotyypin lisäksi pintakasvillisuuden lajikoostumus sekä eräitä luontaista suopuustoa kuvaavia tunnuksia (taulukot 1–3) ja kerättiin kullakin alalla kaksi näytettä 0–10 cm ja 10–20 cm turvekerroksista. Koe-alat jakautuivat kolmen suotyypin välillä seuraavasti:

ruohoinen sararäme	47 koealaa
varsinainen sararäme	107 koealaa
lyhytkortinen räme	44 koealaa

Kerätyistä näytteistä määritettiin laboratoriossa tuorepaino, todellinen tilavuuspaino, orgaanisen aineen tilavuuspaino, tuhkapitoisuus, pH_{H_2O}, sähkönjohtokyky, efektiivinen kationinvaihtokapasiteetti, emäskyllästysaste sekä typen, fosforin, kaliumin, kalsiumin ja magnesiumin kokonaispitoisuudet.

Analyysitulokset ositettiin näytteenottokerroksen ja suotyypin mukaan, luokkia vertailtiin kaksisuuntaisella varianssianalyysillä ja keskiarvotesteillä. Ulkoisten tekijöiden kuten suon pinnanmuodon, pohjamaan- ja kallioperän laadun sekä ilmaston mahdollinen vaikutus pintaturpeen ominaisuuksiin selvitettiin toisaalta osittamalla aineisto edelleen ja toisaalta korrelaatio- ja regressioanalyysien avulla. Milloin mitattujen maatunnusten (taulukot 4–7) tai maatunnusten ja ulkoisten tekijöiden välillä vallitsi jokseenkin selvä johdonmukainen riippuvuus, käytettiin kyseistä muuttujaa regressioselittäjänä muodostetuissa kovarianssimalleissa.

Puuntuotannon edellytykset sararämeillä arvioitiin laskemalla pintaturvekerroksen absoluuttiset ravinnevarastot (kg ravinnetta/ha) totaalipitoisuuksien ja vastaavan luonnollisen tilavuuspainon avulla. Käyttämällä metsänojitusboniteettia ojitusjälkeisen puuston kasvupotentiaalin tunnuksena, muodostettiin monimuuttuja regressiomalli, jossa selittävinä muuttujina olivat pintaturpeen absoluuttiset ravinnevarastot sekä vuotuinen lämpösumma. Yksittäisten makroravinteiden paino mallissa arvioitiin korrelaatio- ja osittaiskorrelaatioanalyysien avulla.

Tutkimuksessa oletettiin että luonnontilaiset sararämeet eivät hydrologisessa mielessä eroa sanottavasti toisistaan ja että pintaturvekerros olisi fysikaalisessa mielessä yhdenmukainen. Analyysitulosten yksityiskohtainen tarkastelu osoitti kuitenkin että sekä luonnollinen tilavuuspaino että maatumisasteen kuvaajana oleva orgaanisen aineen tilavuuspaino kasvavat jonkin verran lyhytkortisista ja varsinaisista sararämeistä ruohoisiin sararämeisiin (kuva 2 ja 3, taulukot 8 ja 10). Turpeen tuhkapitoisuus kasvaa myös selvästi kasvupaikkatyyppisarjassa lyhytkortisten rämeiden 3,2 prosentista 8,0 prosenttiin (kuva 4, taulukko 11).

Todellinen tilavuuspaino ja orgaanisen aineen tilavuuspaino ovat suurimmillaan viljavimpien kasvupaikkojen turpeissa. Tämän vaihtelusuunnan hydrologinen merkitys lienee vähäinen, mutta ravinnepitoisuuksia muunnettaessa absoluuttisiksi määriksi, tilavuuspainolla saattaa olla ratkaiseva merkitys kasvupaikan laatua arvosteltaessa (esim. kalium taulukossa 21 ja kuvassa 28). Itsestään selvänä voidaan pitää kummankin tunnuksen kasvua turpeen pintakerroksesta syvempään kerrokseen. Turpeen tuhkapitoisuus sensijaan ei muutu tässä suhteessa.

Turpeen kemiallisista ominaisuuksista sekä sähkönjohtokyky että happamuus korreloivat molemmissa turvekerroksissa tutkittujen suotyyppien oletetun viljavuussarjan kanssa (kuvat 5 ja 6, taulukot 12 ja 13). Erot kasvupaikkojen välillä ovat tilastollisesti osoitettavissa joskin ne happamuuden kohdalla ovat melko pienet, ainoastaan 0.3–0.6 pH-yksikköä karuimman ja viljavimman kasvupaikan välillä. Koska sekä sähkönjohtokyky että pH, samoin kuin tuhkapitoisuuskin kuvaavat ylimalkaisesti kasvupaikan viljavuutta, antavat saadut tulokset viitteitä ravinteiden suotyypin mukaisista vaihteluista. Toisin kuin yllä mainitut tunnukset turpeen efektiivisen kationinvaihtokapasiteetin ja suotyyppisarjan viljavuuden välillä vallitsi heikko negatiivinen korrelaatio (kuva 7, taulukko 14), joka selittyy kuitenkin turpeen tilavuuspainon vaihtelulla (vrt. kuva 8 ja taulukot 15 ja 8). Emäskyllästysaste kasvaa sen sijaan selvästi viljavimpiin kasvupaikkoihin mentäessä (taulukko 16).

Makroravinteiden, typen, forforin, kaliumin, kalsiumin ja magnesiumin pitoisuudet (mg/g) pintaturpeessa seuraavat yllättävän hyvin tutkittujen suotyyppien perinteistä metsäojituskelpoisuutta. Ravinteiden pitoisuudet nousevat, lukuunottamatta kaliumia, lyhytkortisesta rämeestä varsinaiseen sararämeeseen ja edelleen ruohoiseen sararämeeseen siirryttäessä (kuva 10, 13, 14, 17, 18 ja taulukot 17, 20, 21, 23, 25), ja erot luokkien välillä ovat useimmissa tapauksissa tilastollisesti osoitettavissa. Kaliumin kohdalla keskimääräiset pitoisuudet turpeessa ovat karuimman ja viljavimman suotyypin kohdalla yhtä suuret, mutta varsinaisten sararämeiden kaliumtaso on selvästi kahta muuta tyyppiä korkeampi. Yleisesti ottaen tutkittujen näytteiden ravinnepitoisuudet ovat samaa suuruusluokkaa kuin aikaisemmissa tutkimuksissa todetut. Verrattuna vanhoilta ojitusaluilta saatuihin tietoihin tämän tutkimuksen luonnontilaisten sararämeiden pintaturpeen kaliumtaso on kuitenkin melko korkea.

Maaperämuuttujien välisistä riippuvuuksista (taulukot 4–7) on erityisesti mielenkiintoinen typen ja fosforin välinen korrelaatio (kuva 12, taulukko 19) sekä näiden muuttjien ja turpeen todellisen tilavuuspainon välinen myös positiivinen riippuvuus (kuva 11, taulukko 18). Ensin mainittu korrelaatio selittyy molempien alkuaineiden biologisella pidättymisellä turpeeseen. Typpi- ja fosforipitoisuuksien riippuvuus luonnollisesta tilavuuspainosta on yllättävä, mutta selittynee sekin ravinteiden pidättymistavalla; nähtävästi sekä typpi että fosfori kuuluvat osina hitaasti hajaantuviin orgaanisiin yhdisteisiin. Kaliumin, efektiivisen kationinvaihtokapasiteetin ja todellisen tilavuuspainon välillä vallitsee mielenkiintoinen keskinäinen korrelaatio (kuvat 15, 16 ja 8, taulukot 22 ja 15), joka ilmenee siinä, että kaliumpitoisuuden ja todellisen tilavuuspainon välillä on selvä negatiivinen korrelaatio.

Ravinnepitoisuuksien muuntaminen absoluuttisiksi määriksi pinta-alayksikköä kohti (kuva 28) paljastaa eräitä mielenkiintoisia seikkoja. Absoluuttisesti ilmaistuna turpeen kaliumtaso seuraa kasvupaikkatyyppisarjan oletettua paremmuusjärjestystä ja erot tutkittujen turvekerrosten välillä ovat samalla tasoittuneet. Tämä antaa aihetta korostaa tilavuuspainon merkitystä kasvupaikan laatua arvioitaessa. Joskaan tilavuuspaino sellaisenaan ei ilmennä kovin hyvin kasvupaikan viljavuutta, sen vaikutus sekä ravinnepitoisuuksiin että absoluuttisiin ravinnemääriin on kiistämätön. Tähän liittyy osana myös metsäojituksen pintaturvetta tiivistävä vaikutus, joka selittänee sen, sttä näinkin alhaisilla luontaisilla ravinnemäärillä (kuva 28) on päästy suhteellisen hyvään puuntuotokseen.

Yhteenvetona voidaan todeta, että Cajanderin suotyypit sararämeiden osalta varsin hyvin kuvaavat pintamaan keskimääräistä viljavuutta. Yllämainittu yhdenmukaisuus Cajanderin kasvupaikkaluokituksen kanssa perustuu luokkakeskiarvoihin, ja luokkien sisäinen vaihtelu on huomattava (kuvat 10, 13, 14, 17, 18). Yksittäisen kasvupaikan sijoittaminen oikeaan lokeroonsa jonkun maatunnuksen mittaamiseen perustuvan luokitusjärjestelmän avulla on näin ollen lähes mahdotonta.

Tarkasteltaessa syitä luokkien sisäiseen suureen vaihteluun ilmeni vastoin odotusta, että suon pinnanmuodoilla (tasapinta – mätäs) ei ollut vaikutusta pintaturpeen ominaisuuksiin (kuva 20 ja 21). Vuotuisen lämpösumman ja eräiden pintaturpeen ominaisuuksien välillä ilmeni sen sijaan selvää riippuvuutta (kuvat 22–27). Tarkastelun pääpaino kohdistuu aineiston epähomogeenisen jakautumisen johdosta erityisesti varsinaisiin sararämeisiin ja huomio kiinnittyy turpeen kaliumpitoisuuden pienenemiseen lämpösumman noustessa. Syyt tähän on arvioitu löytyvän efektiivisen kationinvaihtokapasiteetin ja todellisen tilavuuspainon samansuuntaisissa vaihteluissa lämpösumman suhteen. Viitteitä siihen, että suota ympäröivä kallioperä tai kivennäismaa olisi aiheuttanut mainitut vaihtelut tai eräiden muiden tunnusten kohdalla regressiokuvaajan minimin lämpösumma-alueella 1000–1200 dd ei löytynyt. Pohjamaan alkuperämateriaalin vaikutus on kuitenkin hyvin vaikea todentaa, joten tätä mahdollisuutta ei voitu lopullisesti sulkea pois. Tutkittujen ulkoisten tekijöiden vaikutus luokkien sisäiseen vaihteluun on kuitenkin vähäinen verrattuna saman suotyypin sisällä esiintyvään pintakasvillisuuden sisäiseen vaihteluun. Tästä johtuva aineiston hajonta on huomattava, sillä aineisto ositettiin kuvion suotyypin eikä yksittäisen koealan pintakasvillisuuden mukaan.

Tarkasteltaessa kasvupaikkojen puuntuotospotentiaalin ja pintaturpeen ravinteisuuden välistä riippuvuutta huomataan, että metsänojitusboniteetti selittää 10–30 prosenttia yksittäisten makroravinteiden vaihtelusta (kuva 29–33, taulukko 31). Osittamalla aineisto edelleen lämpösumman mukaan selitysasteet nousivat eräissä tapauksissa yli 40 prosenttiin. Korkeat selitysasteet aiheutuvat mitattujen tunnusten multikollineaarisuudesta (vrt. taulukko 30). Jos toisaalta muodostetaan monimuuttujamalli jossa pintaturpeen makroravinnemäärillä selitetään kasvupaikan metsänojitusboniteettia, selitysaste nousee hieman yli 50 prosenttiin. Lisäämällä malliin lämpösumma riippumattomaksi muuttujaksi, selitysaste nousee aina 85 prosenttiin (taulukko 32).

Muodostetun mallin kokonaisselitysaste on huomattavan korkea ja viittaa siihen, että suoranaisesti mitattujen maatunnusten avulla on mahdollista rakentaa kasvupaikkaluokitusjärjestelmä, vaikka vahvan kollineaarisuuden vuoksi ei voidakaan tehdä johtopäätöksiä yksittäisten selittävien muuttujien keskinäisestä järjestyksestä. Suotyyppikohtaisen viljavuusindeksin korvaaminen kasvupaikkakohtaisilla viljavuustunnuksilla näyttää siten mahdolliselta.

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O.D.C. 114.2 + 181.33–4 + 542.

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Seloste: Pintaturpeen viljavuustunnukset suhteessa kasvupaikkatyyppiin ja puuston kasvupotentiaaliin.
ACTA FORESTALIA FENNICA 1972, 77 p. Helsinki.

Bulk density, volume weight of organic matter, ash content, acidity, electric conductivity, effective cation exchange capacity, degree of base saturation and total contents of macronutrients were determined from surface peat from virgin sedge pine mires.

By grouping the data according to plant sociological site types clear relationships with most of the variables were obtained. Among the macronutrients only potassium did not follow the quality gradient of the site types. The conclusion is that the Cajanderian plant sociological site calassification satisfactorily well reflects the average soil properties in the site type series studied. Within site type variation was, however, considerable and highly complicate site ordination based on measurings of soil properties. The effect of external factors on the properties of peat could in particular be seen as a negative relationship between annual accumulative temperature and effective cation exchange capacity as well as total content of potassium.

The absolute amounts of macronutrients in peat from the sedge pine mires were low. In comparison with minimum requirements given for timber production on drained peatlands the most fertile sites only showed an adequate nutrient economy. As forest drainage of the sites studied generally has resulted in a reasonable timber production, either the minimum requirements are taken on the higher side or drainage has induced changes in the peat mass and volume of the rooting zone which affect the nutrient economy.

In multiple regression models the absolute amounts of macronutrients explained up to 50 per cent of the quality index of the sites studied. Addition of annual accumulative temperature as an independent variable increased the degree of explanation to above 85 per cent. The models indicate possibilities to forecast post drainage timber production on the basis of soil data from virgin sites.

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