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SITE CLASSIFICATION IN ESTIMATION OF FERTILIZATION EFFECTS ON DRAINED MIRES

KASVUPAIKKOJEN LUOKITUS
LANNOITUSVAIKUTUKSEN ARVIOINNISSA
OJITETUILLA RÄMEILLÄ

Carl Johan Westman

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Seloste

KASVUPAIKKOJEN LUOKITUS LANNOITUSVAIKUTUKSEN ARVIOINNISSA OJITETUILLA RÄMEILLÄ

HELSINKI 1987

WESTMAN, C. J. 1987. Site classification in estimation of fertilization effects on drained mires. Seloste: Kasvupaikkojen luokitus lannoitusvaikutuksen arvioinnissa ojitetuilla rämeillä. Acta Forestalia Fennica 198. 55 p.

Multivariate methods are used to classify pine mires on the basis of edaphic properties into fertility groups in order to appraise the effect of fertilization in relation to site fertility. The data is based on two field inventories of a NPK fertilization experiment in which 2624 sample trees on 164 sample plots from 19 experimental fields were measured. The edaphic properties (total contents of nutrients and related properties) are based on 1350 volumetric sub-samples combined into two data sets representing 25 non-fertilized control plots and 93 plots with Scots pine dominated tree stand and a peat deposit > 30 cm. Needle samples were collected from 465 sample trees.

In a DECORANA ordination, based upon standardised volumetric soil variables N-P and acid-base gradients jointly describing trophic status were distinguished. Mainly on the basis of these two gradients a TWINSPAN analysis divided the material into five edaphic groups. To independently allocate sample plots into fertility groups, discriminating multiple regressions were formed using the TS edaphic groups as class variable.

The effect of N, P, K, NP, NK, PK, and NPK tratments upon tree growth was estimated on the bases of change in relative basal area increment during two growth periods. During a five year period immediately after fertilization N and P treatments evoked the strongest increase in growth. On the nutrient poor sites the effect was almost double that on the fertile sites. The effect of N was short lasting while the P treatment still affected growth 5–11 years after fertilizer application. Although K treatment had little influence upon tree growth needle samples collected 11 years after fertilization indicated increased K uptake on fertilized plots.

Generally the effect of fertilization on absolute stand volume growth was, however, small. During the 11 year study period the total increase in growth gained with NPK and was some 3–4 m^3·ha^{-1}. Despite strong relative response of individual sample trees, due to low stand volume fertilization (and drainage) had practically no effect upon volume growth on the sites of lowest fertility.

Tutkimuksessa selostetaan menetelmää, jossa kasvupaikkoja luokitellaan niiden maaperäominaisuuksien mukaan. Luokitusta sovelletaan arvioitaessa NPK-lannoituskäsittelyjen vaikutusta. Aineisto perustuu kahteen maastomittaukseen, joissa mitattiin 2624 koepuuta 164 koealalla 19 koekentällä. Maaperäominaisuudet (turpeen kokonaisravinnepitoisuudet ja niihin liittyviä tunnuksia) pohjautuvat 1350 osanäytteeseen, joita yhdistettiin kahdeksi aineistoksi siten, että niistä toinen kuvaa 25 lannoittamattoman kontrolliruudun ja toinen 93 mäntyvaltaisen (turvetta > 30 cm) koeruuden ominaisuuksia. Neulasnäytteitä kerättiin 465 koepuusta.

DECORANA-analyysissä, jossa käytettiin standardoituja volumetrisiä maaperätunnuksia muuttujina, erotettiin N-P ja happo-emäs gradientteihin perustuva trofiasarja. TWINSPAN-analyysissä koeala aineisto jakautui viiteen maaperälliseen ryhmään. Jotta riippumattomalla tavalla voitaisiin luokitella kasvupaikkoja viljavuusluokkiin, muodostettiin erottelevia regressioita käyttämällä TS-maaperärymiä luokkamuuttujina.

N, P, K, NP, NK, PK ja NPK -käsittelyjen vaikutukset kasvuun arvioitiin koepuiden pohjapinta-alan kasvuprosentin muutoksena kahden kasvujakson aikana. Välittömästi lannoituksen jälkeen käsittelyt, jotka sisälsivät typpeä ja fosforia, aiheuttivat voimakkaimman lisäyksen koepuiden kasvussa; karuilla kasvupaikoilla reaktio oli lähes kaksinkertainen verrattuna viljavimpiin kasvupaikkoihin. Typen positiivinen vaikutus oli lyhytaikainen ja toisella kasvujaksolla ainoastaan P-käsittely näytti vaikuttavan puiden kasvuun. Vaikka K-käsittelyn vaikutus oli vähäinen kasvun kannalta, oli neulasten K-pitoisuus vielä 11 vuotta lannoituksen jälkeen korkeampi K-lannoitetuilla ruuduilla.

Johtuen koekanttien puuston pienuudesta lannoituksen ja ojituksen vaikutus tilavuuskasvuun oli vaatimaton. Parhaimmiksi osoittautuneet lannoituskäsittelyt (NP ja NPK) antoivat 11 vuoden aikana ainoastaan 3–4 m^3 · ha^{-1} suuruisen lisäyksen kasvussa. Karuimmilla ja samalla vähäpuustoisimmilla kasvupaikoilla parannustoimenpiteitten vaikutukset olivat mitättömät.

Keywords: edaphic properties, needle analysis, multivariate methods, NPK fertilization.
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PREFACE

Some fifteen years ago I became involved in a NPK fertilization experiment on recently drained mires in north Finland, established in 1970 by Professor Kustaa Seppälä and Head forester Lauri Vaara. In 1974, a forestry inventory and soil sampling on the experimental fields had been carried out, and the experiment was due to be reinventoried around 1980. At the same time I was looking for sample plot material in which both stand growth and edaphic properties had been measured. The aim was to evaluate previously formed regressive models, which predicted post drainage potential stand production on the basis of total nutrient contents in the peat. It was therefore decided to include this aim with the reinventory of the NPK experiment. Consequently, in 1981, intensive field sampling of the experiment was carried out.

The present study deals with the overall results from the two field inventories of the fertilization experiment. In the estimation of the fertilization effect the classification of the material into fertility groups based on the forest worker's assessment of peatland site type proved to be unreliable and edaphic properties of the sites became of particular importance. The soil properties of the sample plot material is therefore extensively used to reclassify the material.

During my work I have received kind help from severel persons and institutions. Miss Kerttu Härkönen and Mr. Jukka Pasonen led the field inventory groups in 1981, and also prepared preliminary reports from the inventory. During the field work valuable support was given by the staff of Kemijärvi forest amelioration district. All the chemical analysis of the soil and needle sample material has been done in the Department of silviculture under the supervision of Mrs. Silja Aho.

The manuscript was read at various stages by Dr. Jukka Laine, Dr. Michael Starr and Professor Juhani Päivänen. Dr. Michael Starr also assisted by revising the English text.

The Finnish Academy of Science and Letters provided me with a research post and financial support for the project. The University of Helsinki, Department of silviculture and the Kemijärvi forest amelioration district board also contributed financial support.

I wish to express my best thanks to all these persons and other not mentioned and institutions for all their kind help.

Helsinki, February 1987

Carl Johan Westman

1. INTRODUCTION

The low contents of phosphorus and potassium in peat in relation to tree stand nutrient demand on drained mires are well known. (e.g. Westman 1981). The potassium content is particularly low in comparison to the nutrient fraction bound in the annual net production of middle aged Scots pine (*Pinus sylvestris*) stands (Mälkönen 1974). However, in Mälkönen's material the total amounts bound in the tree stand biomass during a 40–50 year period are clearly smaller than indicated by the annual uptake. A similar trend can be seen in the values given by Bringmark (1977). Thus efficient nutrient translocation within the crown and recycling within the site enables reasonable stand growth in conditions were soil nutrient contents are low. The capacity of the vegetation to bind and recycle nutrients is also indicated by growth effects lasting 10–15 years after fertilization with easily mobile potassium (e.g. Paavilainen & Simpanen 1975, Paavilainen 1978). On peatlands, the importance of deeper peat layers is emphasized after drainage because of changes in the depth and bulk density of the rooting zone although not marked (Heikurainen 1955), increases the amount of nutrients immediately available. The increase in bulk density, resulting from accelerated humification and the collapse of the surface peat structure with decreasing soil water content and increasing mass of the growing tree stand, increases the amount of nutrients available per unit volume of soil.

To compensate for the low nutrient content in peat, fertilization is occasionally carried out in association with drainage. Fertilization recommendations are based on the natural nutrient contents of peat determined as peatland site type, and consequently PK fertilization is the most commonly used treatment on drained mire sites. However, on the poorest sites very slow microbiological decomposition and a high C/N ratio limit the release of nitrogen. In addition to potassium and phosphorus, nitrogen is thus recommended when fertilizing mire sites with fertility lower than that of tall sedge pine swamps (Paavilainen 1979a). According to Heikurainen (1984) the limit occurs on sites of even lower fertility. Although a climatic gradient gives rise to marked changes in the rate of organic matter decomposition (e.g. Berg et al. 1984) and stand productivity (e.g. Heikurainen and Seppälä 1973), fertilization recommendations have hitherto been the same for comparable sites in both south and north Finland. Nutrients other than N, P, and K have not been considered until the last decade, when the application of also micronutrients has been recommended (e.g. Veijalainen 1983).

In 1970 a comprehensive N P K fertilization experiment was established in north Finland on recently drained pine mires consisting of some of the more common peatland site types. The aim of the experiment was to study the nutrient requirements of drained peatland forests in north Finland. Preliminary results concerning the growth period 1970–74 indicated an unexpected positive effect of nitrogen on some of the peatland site types (Seppälä & Westman 1976). Potassium appeared to have very little effect upon growth. These results were disputed by Paavilainen (1978), who did not consider climatically dependent difference in nitrogen availability in peat from the sedge mires to be of importance (see also Paavilainen & Simpanen 1975). While nitrogen and phosphorus are almost exclusively bound in organic compounds and their availability primarily determined by biological mineralization processes, potassium exists mostly as an easily exchangeable cation and its availability is mainly influenced by soil physico-chemical processes (e.g. Kivinen 1933, Kaila 1956a, 1956b, Starr & Westman 1978, Westman 1981). Consequently the availability of these nutrients is affected differently by changes in climate and by drainage. Forest fertilization experiments (Möller 1978, Heikurainen et al. 1983, Heikurainen & Laine 1985) and agricultural field experiments on peat soils (Anttinen 1951, Salonen 1958, Pessi 1966 and 1971) show an increasing nitrogen demand by the crop when moving towards more unfavourable (i.e. colder) climatic conditions. Recent results by Paavilainen (1984) confirm a demand of additional nitrogen when refertilizing relatively fertile sites in north Finland. Westman (1979) found that, within peatland site type there is a significant negative correlation between annual accumulative temperature sum and potassium content in peat.

During the second inventory of the experiment carried out in August 1981, it became evident that the identification of site type (at the time of drainage) of some of the experimental fields had been incorrect. This had been compounded by assigning the average peatland site type of a stand compartment as a whole to the experimental field, and not having taken into account the within site heterogeneity. The original peatland site type classification of the material was therefore considered unreliable, which may have affected the interpretation of the 1974 inventory (Seppälä & Westman 1976). In this final report it was consequently necessary to evaluate the site fertility of the experimental fields and, if necessary reclassify the sample plots into site fertility groups.

The Finnish site type classification (Cajander 1909, 1913, 1921, 1949), which is the basis for site fertility assessment, is primarily intended for sites with undisturbed surface vegetation developed under mature stands. After drainage, however, changes in soil processes alter the relationships between site type and edaphic properties. On recently drained sites and sites with only little change in soil properties after drainage, the original peatland site type may be derived from the surface vegetation. For old drained forests only a few coarse site types are identified (Lukkala 1929a, 1935, Sarasto 1957). Because of the varying effect of drainage and fertilization upon the surface vegetation, and the apparent between experimental field variation in fertility and the within field heterogeneity it was decided to solve the classification problem by applying some alternative method.

Needle contents of nutrients have been studied as a basis for forecasting the growth response to fertilization (e.g. Paarlahti et al. 1971, Veijalainen 1977). The interpretation of needle nutrient concentration data is, however, difficult and requires a comprehensive knowledge of the contents of all important nutrients and corresponding tree growth prior to fertilization.

Kaunisto (1982) has used the peat nitrogen content to distinguish between sites with satisfactory nitrogen economy and sites which require nitrogen fertilization. Lipas (1985) also used soil nutrient data and multivariate regression techniques to evaluate fertilizer input – growth response on mineral soil sites. However, multicollinearity and non-normal variable distributions are serious problems when applying multiple regression analysis to edaphic factors in site productivity studies, and more so when applying the regression models to other independent data. Thus the production potential indices calculated according to the multiple regressions suggested by Westman (1981) did not prove useful in reclassifying the present study material. However, a large number of variables can be combined to a limited number of orthogonal axes (gradients) using numerical ordination techniques (Gauch 1982). Although some information is lost through the simplification and interpretation of the gradients created may not be simple, fewer axes are easier to handle than the original multidimensional space. Detrended correspondance analysis, decorana, (Hill 1979a) and the hierarchical two way indicator species analysis, twinspan, (Hill 1979b) which uses the same iterative procedure as in decorana, are considered to be the most robust methods in the recent generation of ordination and classification techniques. Thus it was decided to apply decorana (DCA) and twinspan (TS) to soil data to classify the experimental fields and sample plots.

The aim of the present study is to investigate the growth increase resulting from various fertilizer treatments on some important peatland site types in north Finland. The effect of drainage and fertilization upon sample tree increment and stand volume growth in relation to soil fertility is appraised. The study material consists of a 2^3-factorial NPK fertilization experiment in northeastern Finland.

In order to fulfill the aim it is first necessary to assess whether the peatland site type determined prior to drainage is a satisfactory measure of site fertility. For this purpose the edaphic properties of the material are evaluated, and the sample plots classified by applying the twinspan multivariate technique and discriminant analysis to the soil data.

2. MATERIAL

21. The fertilization experiment

The research material consists of an NPK fertilization experiment on mire sites in northern Finland. The mires were drained for forestry production purposes within a 6 year period before the experiment was established in 1970. Initially, 27 experimental fields were laid out; each field consisting of at least one complete 2^3 factorial block, i.e. eight plots with the following treatments N, P, K, NP, NK, PK, NPK, and one non-fertilized control plot. Fertilization with 100 kg $\cdot$ ha^{-1} nitrogen, 44 kg $\cdot$ ha^{-1} phosphorus and 83 kg $\cdot$ ha^{-1} potassium was undertaken in mid-June 1970. Ammonium nitrate with lime (26 % nitrogen), rock phosphate (14.5 % phosphorus) and potassium chloride (49 % potassium) were used as fertilizers. Due to various land management measures only 23 and 19 experimental fields remained intact for the inventories in 1974 and 1981. The location and general data describing the experimental fields/sites are given in Figure 1 and Table 1.

The annual accumulative temperature sum varies between 770 and 860 d.d., which according to Heikurainen and Seppälä (1973), implies a production potential of approximately one third of that on corresponding sites in southern Finland. Long term (1961–80) average meteorological data (Heino & Hellsten 1983) further stress the unfavourable climatic conditions of the region:

Length of growing season	125	days
July mean temperature	+14.1	°C
February mean temperature	−13.2	°C
Annual precipitation	530	mm
Proportion of snow	47	%.

The peatland site type (nomenclature according to Laine et al. 1986) of each experimental field was determined as the average type for a stand compartment by the local forester in association with the drainage planning (Table 1). Most of the experimental fields were pine growing, only two were spruce dominated. With two exceptions, the peat layer was shallow to moderate (<1.0 m). The potential productivity of the sites expressed by the site quality index (Heikurainen 1973a) varied from 1.0 for the least fertile site to 3.2 for the most fertile site, 1.8 being the median site quality index (scale 0 to 10).

Two tree stand inventories of the experiment were made, in August 1974 and August 1981. In the first inventory the tree stand of each individual sample plot was described generally by measuring mean height and basal area. In addition 16 sample trees per plot (here after in the text referred to as the sample trees) were selected by using a relascope, and permanently marked. The following measurements were taken from each of these sample trees:

Variable	Accuracy	
1) diameter at 1.3 m height	1.0	mm
2) diameter at 6.0 m height	1.0	cm
3) height of tree	10	cm
4) height growth 1970–74	10	cm
5) height growth 1965–69	10	cm
6) thickness of bark at 1.3 m height	1.0	mm.

Radial growth during two five year periods prior to the first inventory (1965–69 and 1970–74) were determined from borings taken from the sample trees with a breast height diameter greater than 3.5 cm.

In the second inventory (1981) height growth since the first inventory, and remeasurements of variables 1 to 3 were taken from a total of 2624 sample trees on 164 sample plots from the 19 experimental fields still intact (Table 1, Appendix 1). The vast majority of the sample trees were Scots pines *(Pinus sylvestris)* with only a minor number of Norway spruce *(Picea abies)* and birch *(Betula pubescens)* sample trees. Further, in the inventory in August 1981, all trees on each sample plot were tallied into diameter classes. A description of the tree stand on each sample plot is given in Appendix 1.

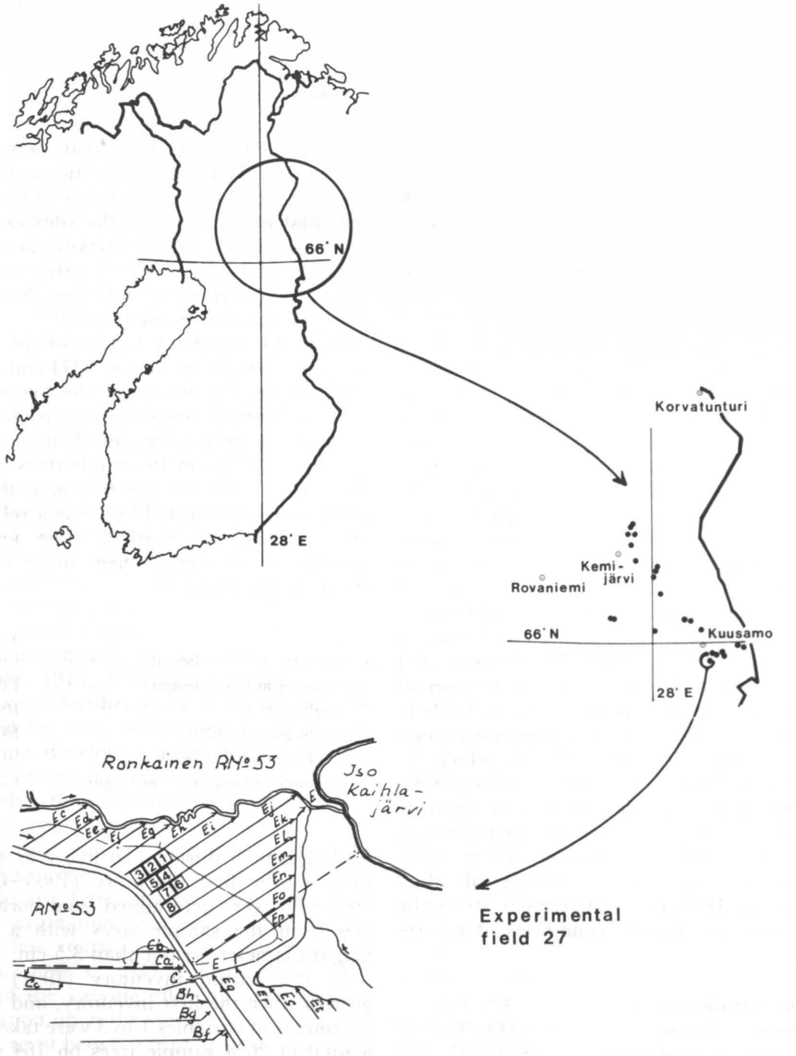

Figure 1. Location of experimental fields. Each dot represent one experimental field consisting of at least eight sample plots. The drainage network and sample plot lay out of experimental field 27 is presented as an example.

Table 1. Location and description of experimental fields in the research project.

Experimental field	Locality (Parish)	Level above sea, m	Temperature sum, d.d.	Peat Depth, m	Year of drainage	Peatland site type 1)	Soil sampling 1974	Soil sampling 1981	Tree stand inventory 1974	Tree stand inventory 1981
1	Kemijärvi	245	825	0.2	1968	PsK	+		+	+
2	Kemijärvi	245	825	0.3	1968	PsR	+		+	+
3	Kemijärvi	200	858	0.3	1965	PsR	+		+	+
4	Kemijärvi	200	858	0.2	1965	KgK	+		+	
5	Kemijärvi	255	808	>1.5	1970	VSR	+	+	+	+
7	Kemijärvi	240	828	>1.5	1970	IR	+	+	+	+
10	Kemijärvi	205	853	0.5	1966	PsR	+	+	+	+
11	Kemijärvi	205	853	0.3	1966	PsR	+		+	+
12	Kemijärvi	205	853	0.5	1966	LkR	+		+	+
13	Salla	250	818	0.5	1966	VSR	+	+	+	+
14	Posio	200	860	0.7	1968	PsR	+	+	+	+
15	Posio	200	860	0.5	1968	KR	+	+	+	+
16	Kuusamo	250	800	0.8	1970	RaR	+	+	+	+
17	Kuusamo	255	800	0.5	1970	RLR	+		+	
18	Posio	250	820	1.0	1969	PsR	+	+	+	+
20	Kuusamo	270	790	1.2	1970	VLR	+	+	+	+
21	Kuusamo	270	800	0.7	1969	LkR	+		+	
22	Kuusamo	260	805	1.0	1969	RaR	+	+	+	+
23	Kuusamo	260	805	0.6	1970	LkR	+	+	+	+
24	Kuusamo	260	805	0.4	1970	VSR	+		+	+
25	Kuusamo	260	800	0.2	1968	PK	+		+	+
26	Kuusamo	260	800	>1.5	1968	VSN	+			
27	Kuusamo	290	770	0.4	1968	PsR	+	+	+	+

1) peatland site type nomenclature according to Laine et al. 1986.

22. Soil and needle data

During both inventories soil samples were collected. The 1974 sampling was aimed at describing generally the experimental field and thus samples were only extracted from the unfertilized control plots (i.e. 25 plots). In 1981, the aim of the sampling was to investigate the relation between soil and tree stand properties, and to test regression models presented by Westman (1981). The soil sampling was restricted to plots with a peat deposit thicker than 0.3 m and with tree stands dominated by Scots pine (i.e. 93 out of 164 available plots listed in Appendix 1). The 1981 sampling included both fertilized and non-fertilized sample plots.

On both occasions volumetric composite samples consisting of randomly located subsamples were extracted from each plot, but the sampling procedure was different. In 1974, the soil sample points were related to the 16 permanent sample trees. Thus 16 soil cores were extracted from the 0 to 20 cm peat layer and, with two exceptions, composited into a single sample per plot. To estimate within plot variation the cores from the control plots of experimental fields 1 and 15 were treated as separate samples. In 1981, the number of sampling points was decreased to 10 and located at random points along the south-north diagonal of the plot. The sampling depth was also increased to 30 cm. Further, in 1974 the volumetric sample was taken by hitting a sampler with known square cross-section area into the peat, while in 1981 the sample was obtained by rotating a slightly conical saw-toothed cylinder into the peat.

From the soil samples, overall descriptive variables: bulk density, ash content, pH, cation exchange capacity and base saturation, and total contents of macro- and micro-nutrients were determined. All analyses were performed after drying the sample to constant mass (105 °C) and homogenizing by milling in a hammer mill fitted with a 2 mm bottom sieve. The results are expressed on a volumetric basis (Westman et al. 1985). Laboratory procedures were somewhat different on the two sampling occasions, but the methods were essentially the same. The bulk density of the sample was obtained from the undisturbed sample volume and corresponding dry mass. The ash content was determined by ashing the sample at ca 250 °C and thereafter igniting the residue at 550 °C for two hours. pH was determined with a double glass electrode from a 1:2.5 (v/v) soil – water slurry after standing for 24 hours. The cation exchange capacity (CEC) was determined by a 1:50 (w/v) extraction with 1–N KCl (Kaila 1971, Nômmik 1974). From aliquots, calcium and magnesium were titrated with NaEDTA and hydrogen and aluminium titrated with NaOH (Heald 1965, McLean 1965). The sum of these cations was taken as total effective cation exchange capacity, and the percentage proportion of calcium and magnesium as the degree of base saturation. The total content of nitrogen was determined by the macro-Kjeldahl method using a catalyst mixture of Na_2SO_4 and Se, 133 mg and 0.83 mg respectively, per added millilitre of H_2SO_4 (Bremner 1965).

The determination of the other macro-nutrients differ between the 1974 and 1981 samplings. In the former, the contents of total phosphorus and potassium were determined by a somewhat simplified analysis for organic material. The peat sample was ashed and ignited as above for ash content, and the residue dissolved in hot 0.5–N HCl on a water bath. From this solution phosphorus was determined with the molybdenumblue method (Kaila 1955) and potassium photometrically with an EEL flame photometer. In the case of the 1981 samples the total content of the macro-nutrients and some micro-nutrients was determined by wet ashing the sample in a $H_2SO_4 - HNO_3 - HClO_4$ acid mixture at a temperature of 212 °C (Allen et al. 1974). From this digest phosphorus and potassium were determined as above and calcium, magnesium, iron and manganese by atomic absorbtion spectrophotometry.

In association with the 1981 inventory, needle samples were also collected on the 93 plots selected for soil sampling. The sampling was performed in the beginning of November 1981. The top most current year's shoots were taken from the five sample trees near to the diagonal along which the soil sample points were located. After drying at 105 °C and homogenizing, the needle mass was analysed for ash content, nitrogen, phosphorus, potassium, calcium, magnesium and manganese. Analysis methods used were the same as those for the 1981 peat samples.

3. METHODS AND CALCULATIONS

31. Edaphic grouping of plots and experimental fields

To evaluate the fertility of the experimental fields and plots and to classify them on the basis of edaphic properties two sets of partly overlapping soil samples were available. In 1974 the 25 non-fertilized control plots were sampled (Table 2) and, in 1981 93 samples were taken from Scots pine dominated plots (Table 3). As the latter data set is more homogeneous and comprehends more soil properties measured this data is used for classifying the sample plots into fertility groups. The 1974 material is used as an independent control data to check the classification based on the 1981 data and for classifying experimental fields not sampled in 1981.

Firstly the soil data was transformed to fit the demands of decorana (Hill 1979a) and twinspan (Hill 1979b) programmes. The volumetrically expressed soil variables were standardised to unitless quantities with a range of 0 to 100 as follows:

$$(X_i - X_{min})/(X_{max} - X_{min}) \cdot 100 \qquad (1)$$

As the distributions in several cases were positively skewed (Table 3) the denominator was substituted as follows:

$$2 \cdot (\bar{X} - X_{min})$$

In this way standardised mean values of approximately 50 could be obtained for all variables.

Using the standardised 1981 soil data, edaphic gradients in the material were derived by ordinating the 93 plots in a decorana analysis. The sample plots were then classified by a twinspan analysis and distinguishable groups of sample plots in the material objectively formed. These groups were then used as classes when forming discriminating multiple regression models (P7M, BMDP 1983) based upon the standardised variables from the 1981 soil data. Finally the sites lacking soil sampling in 1981 were classified according to the material sampled from the non-fertilized control plots in 1974.

32. Preliminary treatment of the stand data

The height and breast height diameter data from the two inventories were checked for outliers and missing data. Stepwise regression models were used to detect such outliers and estimate missing data (PAM, BMDP 1983). Height and/or diameter data had to be estimated in approximately 3 per cent of all the cases. The predicting regressions were formed separately for each fertilization treatment.

From the measured height, diameter, height increment, and increment borings (field inventories 1974 and 1981), the height and breast height diameter of each sample tree for the years 1964 and 1969 were calculated. Correspondingly, individual sample tree basal area was calculated and volume derived using equations based on breast height diameter and height; for Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea* abies) according to Kanninen et al., (1979), and for birch (*Betula pubescens*) according to Laasasenaho (1982). In the calculations only those sample trees were included for which complete data sets for all four years (1964, 1969, 1974, 1981) were obtained, i.e. 2538 trees. The reason for rejecting sample trees was in most cases the small size of the tree. Increment borings were not extracted from trees with a breast height diameter less than 3.5 cm, and in several cases the calculated height and/or breast height diameter became zero or negative in 1969 and 1964. For each sample tree parameter, mean annual increment per cent (ri) was calculated periodwise according to the following equation:

$$ri = \frac{2}{n} \cdot \frac{(x_{t+n} - x_t)}{(x_t - x_{t+n})} \qquad (2)$$

where ri is the mean annual increment per cent, x the corresponding parameter, t and t+n the start and end of the time period and n number of years in the period.

For each experimental field volume tables were computed. The sample plot stand volume was then calculated on the basis of the distributions of trees in diameter classes and the corresponding volume of the diameter class. Volumes for 1974, 1969 and 1964 were obtained by sequential subtraction of the mean volume growth during the corresponding time periods.

33. Estimation of growth response to fertilization

A problem when assessing growth reactions of tree stands on drained and fertilized peatlands is the unevenness in size and age of the trees and the subsequent variation in growth response of individual trees (Seppälä 1969, 1976). Fertility differences among sites accentuate this situation. As drainage in the present experiment was conducted over a six year period prior to fertilization in June 1970, additional complications arise from the effect of both measures being compounded. The separate effect of either treatment is consequently difficult to identify. Further, pre-fertilization growth of the individual experimental fields is differently influenced depending of time of drainage during the period 1965–70. As a consequence of these problems emphasis is laid upon comparisons between sample tree properties rather than estimations of stand properties. Basal area and particularly basal area increment per cent, which are derived from measured breast height diameter and radial increment boring data, are judged to be the most reliable parameters. However, sample plot stand volume and change in volume increment have also been estimated.

Using the data from the non-fertilized control plots, the relationship between sample tree basal area 1964 and the corresponding annual basal area increment per cent during the sequential periods: 1965–69, 1970–74 and 1975–81 is derived. Predictive models using the initial (1964) sample tree basal area as the independent variable were computed separately for two site fertility groups and three drainage periods (PAR, BMDP 1983). The principal function applied is:

$$y = a^{b \cdot x} \qquad (3)$$

The influence of drainage upon sample tree increment is discussed on the basis of the sequential curves predicting basal area increment per cent on the non-fertilized control plots.

Finally, the effect of the fertilizer treatment on sample plot basal area increment per cent is estimated. For each sample tree the non-fertilized basal area increment is predicted on the basis of equation 3. The sample tree response to the fertilizer treatment is then calculated as the difference between the observed sample tree basal area increment per cent (ri_o) and the corresponding predicted value (ri_p). The sample plot estimate (y) is finally calculated as the mean response of n sample trees:

$$y = \sum_{i=1}^{n} (ri_o - ri_p)/n \qquad (4)$$

4. RESULTS

41. Grouping of plots and experimental fields

411. The edaphic properties of the sites: comparison between 1974 and 1981 soil data

Descriptions of the 1974 and 1981 soil sample data are given in Tables 2 and 3, respectively. The two data sets can not be directly compared since the site type distributions are different. The 1974 data cover the total range of site types found on the experimental fields while the 1981 data represent the most abundant site types in the material. Further, the sampled soil layers are of different thickness, and the 1981 soil data contains both fertilized and non-fertilized plots while the 1974 soil data are from control plots only. The difference between the two materials is seen from the bulk density values and other soil vari-

Table 2. Mean edaphic properties and distribution paramenters of the 1974 soil data based on soil samples from 25 non-fertilized control plots.

Variable	$\bar{X}$	s.d.	X_{max}	X_{min}	skewness	kurtosis
bulk density, $g \cdot cm^{-3}$	0.113	0.069	0.359	0.047	2.13***	4.30***
ash, % by mass	9.76	10.51	42.00	1.84	1.64***	1.84
CEC, $\mu eq \cdot cm^{-3}$	28.81	14.57	75.54	12.22	1.75***	2.69***
bases, $\mu eq \cdot cm^{-3}$	12.05	5.61	28.33	5.06	1.01*	0.72
bases, % of CEC	43.66	13.39	78.99	18.89	0.57	0.46
nitrogen, $mg \cdot cm^{-3}$	1.72	1.07	4.83	0.54	1.10*	0.63
phosphorus, $\mu g \cdot cm^{-3}$	87.86	34.61	140.94	13.62	1.26**	0.60
potassium, $\mu g \cdot cm^{-3}$	55.84	38.07	145.78	22.80	1.31**	0.23

Table 3. Mean edaphic properties and distribution parameters of the 1981 soil data based on soil samples from 93 fertilized and non-fertilized sample plots.

Variable	$\bar{X}$	s.d.	X_{max}	X_{min}	skewness	kurtosis
bulk density, $g \cdot cm^{-3}$	0.075	0.020	0.134	0.038	0.56*	0.49
ash, % by mass	4.22	2.73	17.10	1.60	1.66***	3.87***
pH_{water}	3.30	0.308	4.10	2.80	0.80**	0.04
CEC, $\mu eq \cdot cm^{-3}$	26.58	6.09	48.35	13.77	0.732***	1.28***
bases, $\mu eq \cdot cm^{-3}$	12.18	4.37	27.40	3.93	0.66**	0.64
bases, % of CEC	45.32	10.56	71.10	16.89	0.02	–0.54
nitrogen, $mg \cdot cm^{-3}$	1.19	0.61	2.95	0.27	0.87***	0.07
phosphorus, $\mu g \cdot cm^{-3}$	67.29	35.10	193.11	19.40	1.14***	1.01*
potassium, $\mu g \cdot cm^{-3}$	33.34	6.87	54.52	18.31	0.53*	0.37
calcium, $mg \cdot cm^{-3}$	0.250	0.115	0.571	0.063	0.57*	–0.24
magnesium, $\mu g \cdot cm^{-3}$	46.65	19.92	157.81	22.67	2.18***	8.65***
manganese, $\mu g \cdot cm^{-3}$	4.87	2.72	13.32	2.16	1.54***	1.34**
iron, $mg \cdot cm^{-3}$	0.192	0.228	1.143	0.038	2.34***	5.46***

ables. The original pH data from 1974 is not available, but mean pH values of 4.1 and 3.8 for given peatland site type groups in the material are given by Seppälä and Westman (1976). These values are in accord with pH values of natural sedge pine swamps given by Westman (1981) and do not indicate the characteristic post drainage increase in acidity (Lukkala 1929). Thus the much lower mean pH of 3.3 in the 1981 data also indicates a difference between the two data sets. The shallow peat sites not included in the 1981 sampling represent a higher trophy level, on an average, than the 1981 data.

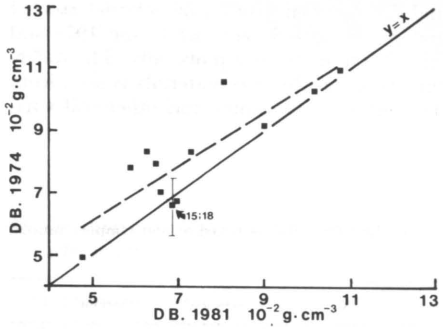

Figure 2. Regression between 1974 and 1981 bulk density values for twelve non-fertilized control plots. 5 % confidence limits are given for sample plot 15: 18. For statistical testing and regression equation see also Table 4.

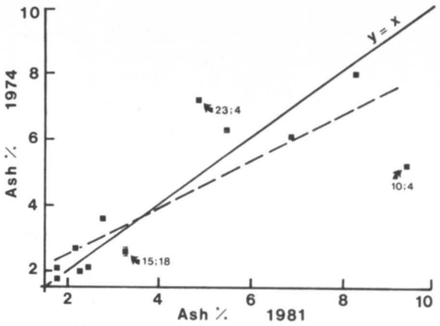

Figure 3. Regression between 1974 and 1981 ash content values for twelve non-fertilized control plots. 5 % confidence limits are given for sample plot 15: 18. Numbered sample plots are referred to in the text. For statistical testing and regression equation see also Table 4.

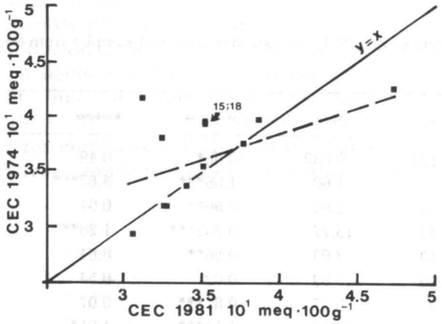

Figure 4. Regression between 1974 and 1981 effective cation exchange capacity values for twelve non-fertilized control plots. 5 % confidence limits are given for sample plot 15: 18. For statistical testing and regression equation see also Table 4.

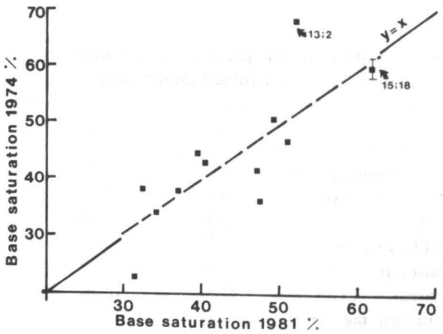

Figure 5. Regression between 1974 and 1981 base saturation values for twelve non-fertilized control plots. 5 % confidence limits are given for sample plot 15:18. Numbered sample plots are referred to in the text. For statistical testing and regression equation see also Table 4.

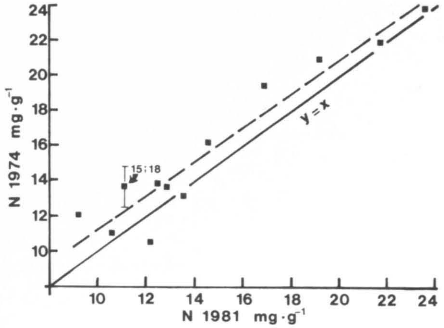

Figure 6. Regression between 1974 and 1981 nitrogen values for twelve non-fertilized control plots. 5 % confidence limits are given for sample plot 15: 18. For statistical testing and regression equation see also Table 4.

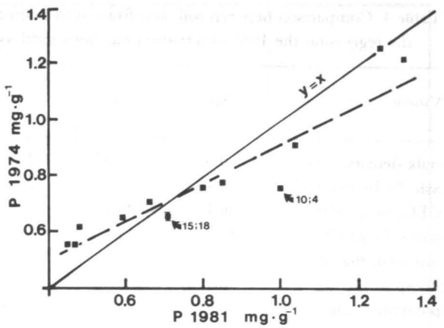

Figure 7. Regression between 1974 and 1981 phosphorus values for twelve non-fertilized control plots. 5 % confidence limits are given for sample plot 15: 18. Numbered sample plots are referred to in the text. For statistical testing and regression equation see also Table 4.

The non-fertilized control plots on twelve of the experimental fields fulfilled the criteria set for sampling in 1981 (dominance of Scots pine, peat layer >30 cm) and were thus sampled again. The 1974 and 1981 data for these plots are directly comparable. Scattergrams of the 1974 and 1981 data are presented in Figures 2 to 8. Regressions and t-tests (P1R and P3D, BMDP 1983) between the 1981 and 1974 data (Table 4) show that there are no significant differences between the two control plot samplings. The reproducibility of the nitrogen and phosphorus values is particularly good. The slight increase in dispersion for phosphorus in comparison to nitrogen may be attributed to contamination with mineral material; plots with a high ash content (10:4, 13:2, 15:18 and 23:4) are scattered. Despite the dispersion in CEC, the reproducibility of the degree of base saturation is good.

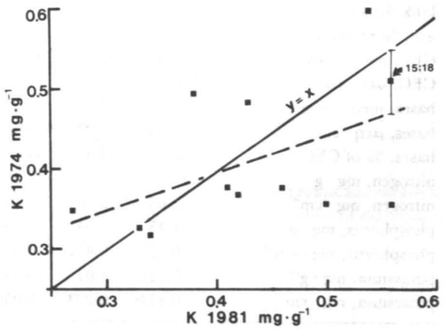

Figure 8. Regression between 1974 and 1981 potassium values for twelve non-fertilized control plots. 5 % confidence limits are given for sample plot 15: 18. For statistical testing and regression equation see also Table 4.

Within plot variation was examined using the sixteen sub-samples from two control plots (17 and 18) belonging to the randomly selected experimental fields 1 and 15 sampled in 1974. The within plot variation is described in Table 5. Unfortunately, both sites have a shallow peat layer, 20 and 50 cm respectively. The influence of varying amounts of mineral soil in the peat can be seen for all the variables measured, particularly when volumetrically expressed. The control plot 18 was also sampled in 1981 and gravimetrical values obtained from the composite sample are included in Table 5 for comparison. Bulk density determined from the 1981 sample falls within the confidence limits calculated on the basis of the 1974 data. However, CEC, degree of base saturation and mean macro-nutrient contents do not fall within the limits, but the failure is marginal in all cases.

Table 4. Comparison between soil data from twelve non-fertilized control plots sampled both in 1974 and in 1981. In the regression the 1981 observation has been used as the x-variable.

Variable	$\bar{X}_{74}$	$\bar{X}_{81}$	t-test		regression		
			t	Prob.	coeff.	const.	r^2
bulk density, g · cm^{-3}	0.082	0.075	1.05	0.31	0.880	0.017	0.73
ash, % by mass	4.14	4.31	0.17	0.87	0.704	1.108	0.68
CEC, meq · 100g^{-1}	36.1	35.4	0.39	0.70	0.498	18.474	0.26
bases, % of CEC	43.7	43.6	0.03	0.98	1.017	–0.615	0.64
nitrogen, mg · g^{-1}	15.9	14.8	0.58	0.57	0.954	1.764	0.91
phosphorus, mg · g^{-1}	0.778	0.803	0.23	0.82	0.684	0.228	0.88
potassium, mg · g^{-1}	0.415	0.433	0.49	0.63	0.483	0.205	0.25

Table 5. Within sample plot variation of soil properties. The variable parameters are based on sixteen samples taken in 1974 on each of the non-fertilized control plots on experimental fields 1 and 15. Experimental field 15 control plot 1981 composite sample values (X_{81}) are also given.

	sample plot 1:17				sample plot 15:18				
Variable	$\bar{X}_{74}$	X_{max}	X_{min}	$s/\bar{X}$	$\bar{X}_{74}$	X_{max}	X_{min}	$s/\bar{X}$	X_{81}
bulk density, g · cm^{-3}	0.154	0.229	0.058	43	0.066	0.104	0.038	29	0.069
ash, % of mass	14.1	33.4	6.5	62	2.59	3.05	2.14	10	3.30
CEC, meq · 100g^{-1}	39.4	46.0	32.4	11	39.8	42.0	34.3	5	38.6
CEC, μeq · cm^{-3}	5.86	9.70	2.21	32	2.60	3.94	1.53	28	. .
bases, meq · 100g^{-1}	16.8	21.5	13.0	16	23.9	27.9	18.3	9	. .
bases, μeq · cm^{-3}	2.45	3.92	1.08	31	1.57	2.47	0.914	29	. .
bases, % of CEC	42.5	48.8	33.8	10	60.1	66.7	53.4	5	62.0
nitrogen, mg · g^{-1}	17.6	21.7	13.3	14	13.7	17.0	9.94	16	11.1
nitrogen, mg · cm^{-3}	2.68	5.18	1.00	42	0.936	1.78	0.378	44	. .
phosphorus, mg · g^{-1}	1.45	2.04	0.905	22	0.706	0.837	0.540	11	0.660
phosphorus, mg · cm^{-3}	0.227	0.411	0.047	47	0.046	0.079	0.023	34	. .
potassium, mg · g^{-1}	0.721	1.01	0.543	21	0.516	0.618	0.335	16	0.560
potassium, mg · cm^{-3}	0.114	0.293	0.056	58	0.033	0.048	0.013	26	. .

412. Edaphic gradients and groups

The research material contains different peatland site types (Table 1), which account for part of the variation in soil properties and the differences between the two data sets. The skewness and kurtosis values in Table 2 and 3, indicate the inclusion of sub-populations related to the different peatland site types. Amongst the soil properties pH, ash content, nitrogen, phosphorus, and, in particular, manganese and iron are clearly positively skewed. For example, in the frequency distribution of the ash content the maximum value is slightly above 40 mass per cent and one fourth of the samples have higher ash value than 14 per cent. In other cases (bulk density, CEC, potassium and magnesium) non-normality is the result of a few extreme observations. In ordination and classification analyses those soil variables with skewed distributions may thus be expected to be efficient discriminators between site groups of different fertility.

To establish edaphic gradients among the experimental fields a decorana (DCA) ordination based on the standardised 1981 soil data was computed. Assuming that the influence of fertilizers on soil chemical data had levelled of during the eleven year period since spreading in 1970, the entire sample plot material (93 plots) was included in the computation. According to the scores given to each sample plot along each of the first three DCA axes, the sample plots are plotted in Figure 9. To interpret the gradients given by the DCA axes, Spearman rank correlations (P3S, BMDP 1983) among the standardised edaphic variables and the axis scores were calculated (Table 6).

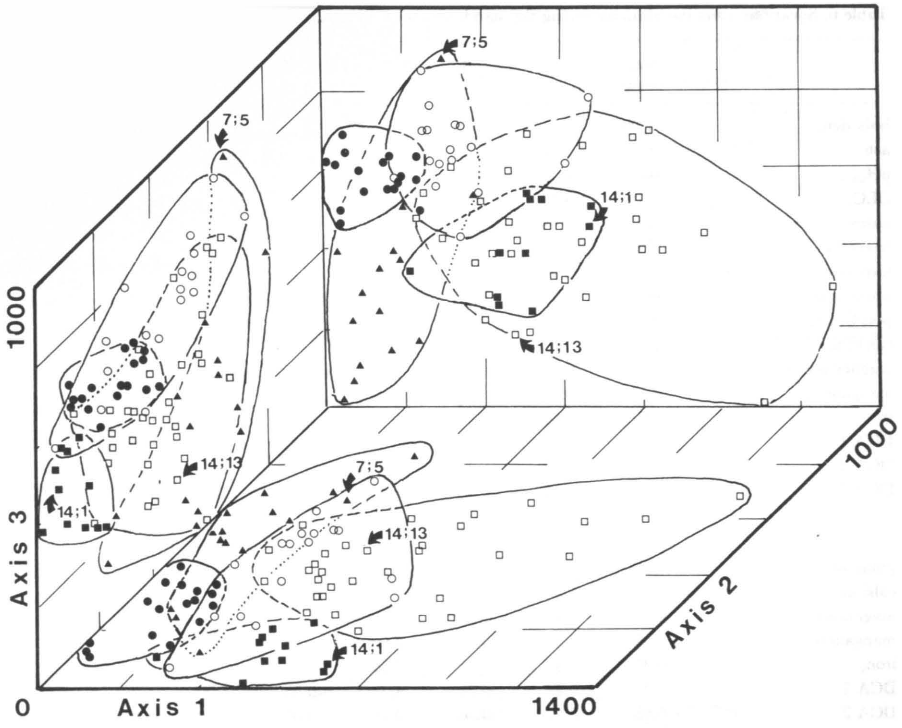

Figure 9. Decorana sample plot ordination using standardised 1981 soil data. Twinspan edaphic groups are indicated by symbols (● = TS 00, ○ = TS 01, ■ = TS 100, □ TS 101, ▲ = TS 11) and the surface projections of each group are encircled. Separately numbered sample plots are referred to in the text.

It appears that the sample plots are related to two main edaphic gradients. DCA axis 1 is strongly correlated to nitrogen and phosphorus contents, but the content of iron also correlates clearly. These same soil variables are related to the bulk density and the ash content of the peat materia, which are also strongly correlated to DCA axis 1. The strong relationship between DCA axis 1 and bulk density and ash content of the peat material may be interpreted as a joint effect of increasing degree of decomposition of the peat material and influence of underlying mineral matter along the gradient. The second and the third DCA axes appear to reflect acid-base gradients. Axis 2 is strongly correlated to the degree of base saturation, and axis 3 correlates to the pH. Thus the three DCA axes reflect differences in trophy within the sample plot material. According to Heikurainen (1953, 1985) the trophy concept is most strongly related to the pH and calcium con-

Table 6. Spearman rank correlations among the standardised edaphic variables and DCA axes scores.

	bulk density	ash	pH$_w$	CEC$_v$	bases$_v$	bases %	N$_v$	P$_v$
bulk den.	1.00							
ash	0.37	1.00						
pH$_{water}$	0.45	0.72	1.00					
CEC$_v$	0.78	0.47	0.35	1.00				
bases$_v$	0.55	0.49	0.59	0.68	1.00			
bases %	0.21	0.33	0.55	0.23	0.84	1.00		
nitrogen$_v$	0.94	0.61	0.53	0.74	0.61	0.31	1.00	
phosporus$_v$	0.82	0.73	0.58	0.71	0.52	0.21	0.89	1.00
potassium$_v$	0.52	0.44	0.39	0.48	0.41	0.22	0.52	0.59
calcium$_v$	0.51	0.52	0.70	0.53	0.86	0.80	0.59	0.51
magnesium$_v$	0.49	0.51	0.70	0.45	0.82	0.80	0.56	0.45
manganese$_v$	0.22	0.54	0.42	0.39	0.33	0.16	0.32	0.46
iron$_v$	0.61	0.64	0.61	0.47	0.47	0.30	0.77	0.72
DCA 1	–0.80	–0.55	–0.25	–0.52	–0.23	0.06	–0.79	–0.75
DCA 2	–0.17	0.20	–0.14	–0.04	–0.49	–0.66	–0.12	0.09
DCA 3	–0.00	0.72	0.76	–0.00	0.38	0.52	0.20	0.28

	K$_v$	Ca$_v$	Mg$_v$	Mn$_v$	Fe$_v$	DCA1	DCA2	DCA3
potassium$_v$	1.00							
calsium$_v$	0.43	1.00						
magnesium$_v$	0.42	0.91	1.00					
manganese$_v$	0.49	0.37	0.27	1.00				
iron$_v$	0.37	0.51	0.51	0.26	1.00			
DCA 1	–0.36	–0.22	–0.21	–0.09	–0.53	1.00		
DCA 2	0.08	–0.50	–0.56	0.45	–0.07	–0.10	1.00	
DCA 3	0.20	0.59	0.57	0.50	0.36	0.04	–0.00	1.00

tent of the peat, but also to the nitrogen content. Puustjärvi (1968) particularly stresses the importance of peat calcium. Although pH and base saturation are most strongly linked to axis 2 and 3, the primary reason for the acid-base gradient is the content of basic elements in the peat (rank correlations in Table 6). Schneider and Westman (1987) have found that trophy also reflect the peat phosphorus content. Potassium is only weakly correlated to axis 1 and not at all to axes 2 and 3 (Table 6). The relationship between the DCA axes and some important soil variables (N, pH and base saturation) is visualized in Figures 10 to 12.

To objectively form sample plot groups a twinspan (TS) analysis was computed from the standardized 1981 soil data (Fig. 13). The first TS division separates the sample plot

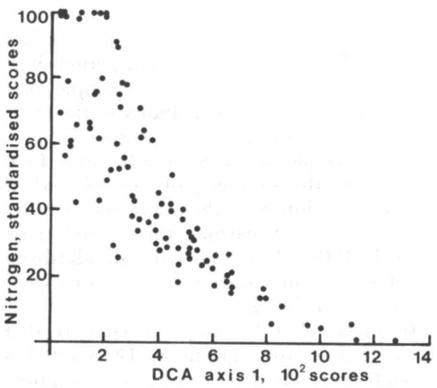

Figure 10. Scattergram of DCA axis 1 scores and standardised volumetric content of nitrogen in the peat.

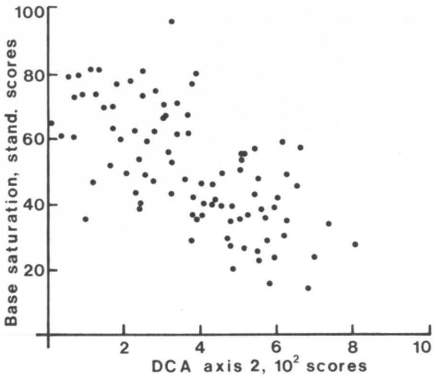

Figure 11. Scattergram of DCA axis 2 scores and standardised base saturation values of the peat.

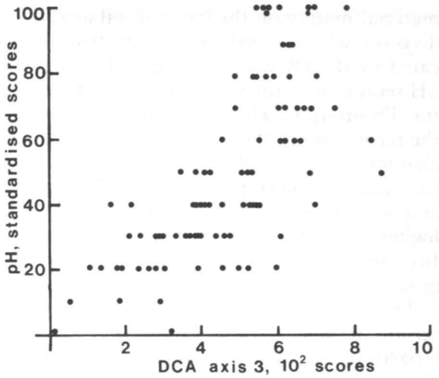

Figure 12. Scattergram of DCA axis 3 scores and standardised pH values of the peat.

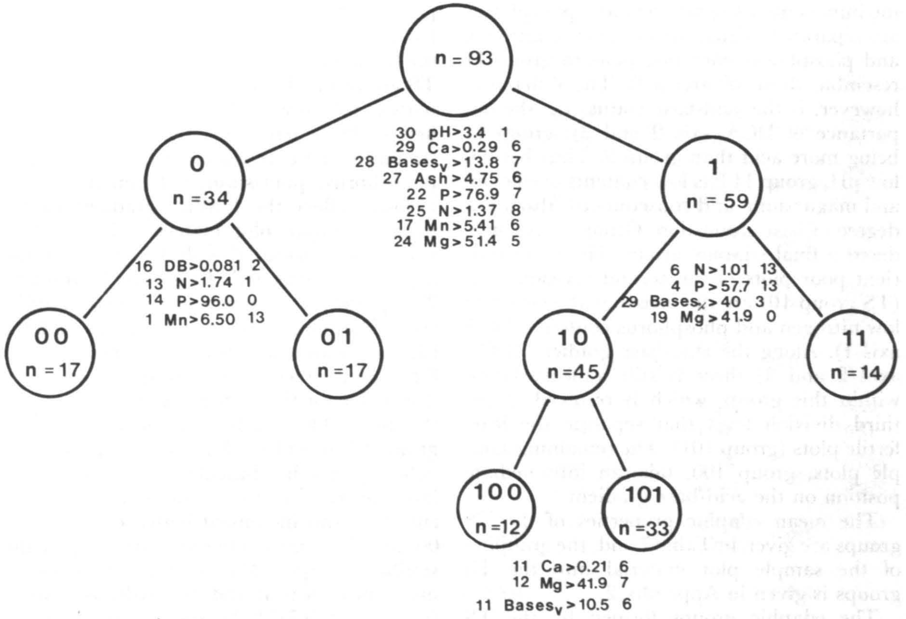

Figure 13. Twinspan classification of sample plot material on the basis of standardised 1981 soil data. At each division level, indicator properties: bulk density (mg · g^{-1}), ash content (% by weight), pH (in water), volumetric content of bases (μeq · cm^{-3}), base saturation (% of CEC), volumetric contents of nitrogen (mg · cm^{-3}), phosphorus (μg · cm^{-3}), calcium (mg · cm^{-3}), magnesium (μg · cm^{-3}), and manganese (μg · cm^{-3}) are given together with number of observations fulfilling respective criterion.

material mainly on the basis of soil acidity, a division which parallels the gradient indicated by the DCA axes 2 and 3. The highest pH scores are, with a few exceptions, found in the TS group 0. This group thus constitutes the fertile end of the site fertility continuum, characterized by relatively high contens of calcium, magnesium, exchangeable bases and ash. This group is also associated with higher contents of phosphorus and nitrogen. Inversely, low pH values are specific for TS group 1.

The second level division of the fertile plots (group 0) separates a group (00) characterized by the highest nitrogen and phosphorus contents, high bulk density and high base element content. The rest of the plots (01) are somewhat less fertile and distinctive with respect to the extremely high manganese contents. These groups (00 and 01) are considered final edaphic groups.

From the less fertile plots of the first TS division level (group 1), the plots with medium contents of nitrogen and phosphorus are separated. Thus, with respect to nitrogen and phosphorus contents, plots in group 11 resemble those of group 0. The difference, however, is the acid-base status (i.e. the importance of DCA axis 2 and 3); group 11 being more acid than group 0. Thus besides low pH, group 11 has low contents of calcium and magnesium, and consequently also a low degree of base saturation. Group 11 is considered a final edaphic group. The other nutrient poor plots of the second division level (TS group 10) are distinctive with respect to low nitrogen and phosphorus contents (DCA axis 1). Along the acid-base gradient (DCA axes 2 and 3) there is still some variation within this group, which is resolved at the third division level that separate the least fertile plots (group 101). The remaining sample plots, group 100, take an intermediate position on the acid-base gradient.

The mean edaphic properties of the TS groups are given in Table 7 and, the grouping of the sample plot material into the TS groups is given in Appendix 2.

The edaphic groups formed by the TS classification are also indicated as surface projections in the DCA ordination (Fig. 9). The most fertile plots, belonging to the TS group 00, are neatly concentrated in an area delimited by low scores along DCA axes 1 and 2 as well as relatively high scores along axis 3. The other TS edaphic groups are separated out along axes 1 and 2. The relationship between groups 00 and 11 is well illustrated, sites in both groups having low scores along axis 1, but group 11 being highly dispersed along axes 2 and 3. The intermediate position of group 100 is also illustrated. Low scores along DCA axis 2 reflect a higher degree of base saturation and intermediate scores along DCA axis 1 and 3 indicate moderate fertility.

In 1981 needle samples were also collected from the sample plots and the results of ash, nitrogen, phosphorus, potassium, calcium, magnesium and manganese determinations are classified according to TS edaphic group (Table 8). Significant differences between the groups are indicated. Needle nutrient concentration data alone, however, does not measure tree nutrient consumption; concentration values need to be related to biomass production and internal bioelement transport. In the present material the mean height increment of the sampled trees is significantly the highest for TS group 00 and the lowest for TS group 11 (Table 8). Needle nutrient contents weighted with the corresponding annual height increment are given in Table 8. Amongst these relative estimates nitrogen, phosphorus, potassium, calcium and magnesium reflect the fertility gradient in the present sample plot material. The highest values are associated with TS group 00 and the lowest values with TS groups 11 and 101. The pattern for manganese is clearly different. The highest relative estimates and the highest mean concentration values are found for sample trees in TS group 01, which is distinctive for the high manganese content of the peat. The needle concentration in TS group 01 is indeed high in comparison to values given by Braekke (1977) and may indicate toxicity, thus explaining the difference in stand increment between TS groups 00 and 01, which otherwise are edaphically similar groups. The correlation between manganese in peat and in needles is positive ($r_{pMn,\ nMn} = 0.715^{***}$), and negative between height increment and manganese in needles ($r_{nMn,\ hi} = -0.316^{***}$). For the other nutrients the relationships between soil and needle contents and height increment are not equally clear. The correlation between peat and

Table 7. Mean and upper and lower 5 % confidence limits of soil properties of the twinspan edaphic groups formed from the 1981 soil sample data.

Soil property	Twinspan edaphic group									
	00		01		100		101		11	
	x̄	conf. lim.	x̄	conf. lim.	x̄	conf. lim.	x̄	conf. lim.	x̄	conf. lim.
bulk density $g \cdot cm^{-1}$	0.101	0.109 0.093	0.076	0.082 0.070	0.070	0.074 0.066	0.057	0.061 0.053	0.090	0.094 0.086
Ash, % of mass	7.56	7.69 7.42	5.81	6.73 4.89	2.67	3.53 1.81	2.63	2.94 2.31	2.82	3.51 2.13
pH_{water}	3.75	3.86 3.64	3.42	3.50 3.33	3.16	3.22 3.09	3.13	3.18 3.07	3.06	3.16 2.95
CEC, $meq \cdot 100g^{-1}$	33.1	35.0 31.2	37.0	40.0 34.0	39.0	41.3 36.7	37.7	39.7 35.8	34.1	38.0 30.7
Bases, % of CEC	52.1	54.4 49.7	49.3	53.6 45.1	49.2	53.6 44.9	39.7	42.3 37.1	32.4	37.3 27.6
N_g $mg \cdot g^{-1}$	21.6	22.3 20.9	17.0	18.4 15.7	12.6	13.3 11.9	11.6	12.3 11.0	15.3	16.4 14.3
N_v $mg \cdot cm^{-3}$	2.18	2.36 1.99	1.30	1.45 1.16	0.89	0.98 0.80	0.68	0.75 0.60	1.38	1.47 1.30
P_g $mg \cdot g^{-1}$	1.22	1.32 1.12	0.93	1.02 0.85	0.61	0.68 0.54	0.72	0.77 0.66	0.96	1.11 0.81
P_v $mg \cdot cm^{-3}$	0.123	0.137 0.109	0.070	0.076 0.064	0.042	0.046 0.038	0.041	0.045 0.037	0.086	0.098 0.074
K_g $mg \cdot g^{-1}$	0.39	0.42 0.35	0.47	0.51 0.43	0.47	0.51 0.42	0.53	0.57 0.49	0.37	0.42 0.33
K_v $mg \cdot cm^{-3}$	0.039	0.043 0.035	0.035	0.037 0.033	0.032	0.034 0.030	0.030	0.032 0.028	0.034	0.038 0.030
Ca_g $mg \cdot g^{-1}$	3.83	4.27 3.39	4.20	4.88 3.52	3.73	4.32 3.15	2.80	3.13 2.47	1.80	2.20 1.39
Ca_v $mg \cdot cm^{-3}$	0.39	0.44 0.33	0.31	0.34 0.28	0.26	0.30 0.22	0.16	0.18 0.14	0.16	0.20 0.13
Mg_g $mg \cdot g^{-1}$	0.71	0.80 0.63	0.68	0.77 0.58	0.68	0.77 0.59	0.61	0.67 0.56	0.36	0.40 0.31
Mg_v $mg \cdot cm^{-3}$	0.073	0.085 0.061	0.050	0.054 0.046	0.047	0.053 0.041	0.034	0.036 0.032	0.032	0.036 0.028
Mn_g $mg \cdot g^{-1}$	0.044	0.050 0.038	0.117	0.144 0.090	0.056	0.070 0.042	0.071	0.085 0.057	0.045	0.053 0.037
Mn_v $mg \cdot cm^{-3}$	0.004	. . . .	0.008	. . . .	0.004	. . . .	0.004	. . . .	0.004	. . . .
Fe_g $mg \cdot g^{-1}$	5.42	6.52 4.33	2.43	3.11 1.74	1.04	1.18 0.90	1.39	1.59 1.19	1.10	1.38 0.82
Fe_v $mg \cdot cm^{-3}$	0.556	0.689 0.423	0.184	0.235 0.133	0.072	0.080 0.064	0.078	0.090 0.066	0.098	0.120 0.076

Table 8. Needle ash and nutrient contents and estimates of nutrient consumption of sample trees according to the twinspan edaphic groups (1981 sample plot material). The estimates are relative values calculated by weighing the concentration data with corresponding mean leader increment (I_h). Bars indicate significant differences at 5 % risk level.

Property F-statistic	Twinspan edaphic group 00	01	100	101	11
			mg · g^{-1} dry matter		
Ash n.s.	19.3±0.50	19.1±0.50	18.9±0.25	18.9±0.41	19.0±0.71
Nitrogen 5.73***	13.6±0.63	11.4±0.24	12.3±0.56	11.1±0.38	10.4±0.59
Phosphorus n.s.	1.39±0.06	1.30±0.06	1.37±0.04	1.30±0.03	1.29±0.07
Potassium 3.92*	3.71±0.15	3.32±0.13	4.07±0.21	3.69±0.08	3.47±0.11
Calcium n.s.	3.17±0.15	3.45±0.12	3.19±0.07	3.25±0.09	3.29±0.17
Magnesium 4.33***	1.02±0.04	1.01±0.03	1.18±0.04	1.10±0.03	1.21±0.06
Manganese 19.51***	0.33±0.03	0.78±0.05	0.46±0.04	0.51±0.03	0.43±0.03
			Relative estimates		
Nitrogen 10.49***	0.55±0.05	0.29±0.03	0.33±0.03	0.31±0.03	0.23±0.04
Phosphorus 5.87***	0.47±0.05	0.28±0.04	0.29±0.02	0.29±0.02	0.23±0.04
Potassium 5.58***	0.43±0.04	0.24±0.03	0.31±0.03	0.29±0.02	0.21±0.03
Calcium 5.28***	0.63±0.06	0.44±0.05	0.41±0.03	0.4 3±0.03	0.35±0.06
Magnesium 4.49**	0.64±0.05	0.41±0.05	0.49±0.03	0.47±0.03	0.41±0.06
Manganese 4.94**	0.37±0.04	0.51±0.05	0.32±0.03	0.38±0.04	0.24±0.03
			Mean annual leader increment, cm · a^{-1}		
I_h 1975–81 7.05***	17.6±1.3	11.1±1.1	11.6±0.9	11.9±0.8	9.4±1.4

needle phosphorus contents is low ($r_{pP,\ nP}$ = 0.226*) and non-significant for nitrogen and potassium. Phosphorus and potassium fertilization, however, still appear to affect needle concentrations (see ch. 433.).

To objectively allocate experimental fields not included in the TS computation above (those where the control plot was sampled in 1974 only), a stepwise discriminant analysis with the TS edaphic group as class variable was used (P7M, BMDP 1983). In a preliminary computation, the standardised 1981 soil data and the axes scores from the DCA ordination were used as independent variables in the stepwise multiple regression. Nitrogen and calcium significantly separated TS groups 100, 101 and 11 from group 00, and group 01 from 101. Manganese, pH and phosphorus increased the degree of explanation of the model, but did not contribute to any further significant differences between the groups (basic equations in Table 9). The DCA scores surprisingly did not, at any stage of the stepwise regression, contribute to the model. When the set of equations (one for each defined TS edaphic group) is applied to a sample plot soil data set, the equation giving the highest y-value denote the edaphic group into which the sample plot would be allocated.

A comparison between the TS calssification and the output from a preliminary discriminant analysis showed that the multiple regressions (basic equations in Table 9) successfully reflected the edaphic TS grouping. All plots from TS group 00 were correctly allocated, and the plots from TS groups 100, 101 and 11 were correctly classified in approximately 90 per cent of cases. Only TS group 01 was difficult to define as more than one third of the plots from this group were wrongly classified into TS groups 00, 100 and 11. From above reasons it is clear that the discriminant analysis functions can be applied for allocating plots not included in the TS analysis.

Total calcium, magnesium and manganese were not determined for the 1974 sample material and the 1974 pH data is no longer available. Thus the independent variables from the 1981 sample material used to develop the discriminating regressions had to be restricted to those variables measured in the 1974 soil sample material (Table 2). The

Table 9. Multiple regression equations formed by stepwise regression analysis for allocating sample plots into twinspan edaphic groups. Basic equations are based on the 1981 soil sample data and simplified equations on the 1974 soil data.

Independent variable	Twinspan edaphic group 00	01	100	101	11	F-value to enter variable
			Basic equations			
			Regression coefficients			
$nitrogen_v$	22.4	10.8	2.51	10.1	2.80	93.75
$calcuim_v$	17.2	17.6	25.2	3.03	2.24	29.41
$manganese_v$	–1.98	8.79	–0.902	2.34	5.56	14.88
pH_{water}	22.4	10.8	2.51	10.1	2.80	11.03
$phosporus_v$	15.0	5.04	–0.842	0.813	17.7	5.22
			Constants			
	–45.1	–23.8	–12.2	–5.66	–15.6	
			Simplified equations			
			Regression coefficients			
$Nitrogen_v$	44.5	24.9	14.9	6.78	16.6	81.18
$phosporus_v$	19.7	6.52	–3.00	3.33	17.5	7.84
$bases_v$	30.1	23.2	17.2	7.62	2.25	6.03
ash %	15.3	14.4	0.843	2.93	1.17	5.55
CEC_v	–19.8	–7.97	7.10	3.39	11.6	4.14
			Constants			
	–42.6	–20.3	–11.0	–4.65	–16.6	

joint effect of exchangeable base cations, ash content, and CEC would tend to compensate for the lack of calcium, magnesium and pH in any case. When the simplified equations (Table 9) were formed on the basis of the 1981 soil sample data, the twelve control plots sampled both in 1974 and 1981, were excluded from the computations. These plots were then used as an independent data set to evaluate the discrimination.

The result of the final discriminant analysis allocation is given in Appendix 2. The recovery of the TS edaphic groups is satisfactory. In comparison to the TS classification only three of the twelve control plots used as an independent data set are located into the wrong group. The allocation of sample plot 7:5 into TS group 11 is understood on the basis of Figure 9. In the scattergram, the plot 7:5 is located in the sector of the 11 group, which overlaps the 01 group projection. The reason for plots 14:1 and 14:13 being missclassified is not clear; in the preliminary computation in which calcium was included, both plots were correctly located. Of the entire sample plot material 13 out of 93 plots were wrongly classified into an adjoining edaphic group.

Finally all the control plots were classified according to the simplified equations (Table 9) and the 1974 soil sample material. Again sample plot 7:5 is allocated into TS group 01, and plot 14:13 into Ts group 100, which is the most frequent TS fertility class on that particular experimental field. On the basis of the 1974 soil data, the plot 14:1 is correctly allocated to TS group 100. In the case of the control plot 23:4, which on the basis of the 1974 soil data and the simplified equations has been classified into the most fertile TS group 00, the site as a whole is rather more fertile than the primary peatland site type (LkR) indicates.

413. Comparison between peatland site type and twinspan edaphic classifications: fertility grouping of the material

In the evaluation of the drainage and fertilization effect upon tree growth (ch. 43.), the sample plots (except the control plots) were firstly allocated into one of the five TS edaphic groups according to the 1981 soil sample data using the simplified discriminating equations (Table 9). All control plots were classified on the basis of the 1974 soil data. As the sample plot material is limited, splitting of the material into five edaphic groups was considered too many. Consequently, in the final evaluation of the amelioration measures the two fertile TS groups (00 and 01) were combined, and the intermadiate TS group 100 combined with the two TS groups (101 and 11) of low fertility. This pooling of the edaphic groups into two main fertility groups also eliminates the influence of possible biases in the edaphic grouping. In comparison to the TS grouping, applying the discriminating functions (Table 9) and pooling the edaphic groups result in a contradicting exchange of only three plots between the fertility groups (Appendix 2). In the case of the control plots 23:4 and 7:5 the allocation to the fertile plot group is even more in accordance with the overall fertility of other plots on the sites than the TS group originally assigned to the plots.

Basal area increment of non-fertilized sample trees (Figures 15 to 19, ch. 431.) illustrate the difference between the pooled fertility groups. On the fertile plots (TS groups 00 and 01) the per cent basal area increment is, but a few irregularities for mostly the small trees, higher than on the nutrient poor sites (100, 101 and 11).

A comparison of the sample plot classifications, according to the original peatland site type assessment in the field prior to drainage, and according to the edaphic TS grouping and disriminant analyses above, is given in Table 10. The peatland site types (Table 10) are ranked according to their trophic status (Heikurainen 1973a) and form a fertility gradient from paludified *Vaccinium myrtillus* spruce forest (KgK) to the *Sphagnum fuscum* pine bog (RaR). An exception in the trophy gradient is, however, made for the KR and LkR which are swapped. The reason for the exchange in order is that in Seppälä and Westman's (1976) preliminary evaluation of the experiment, VLR, RLR, VSR, PsR and LkR were considered to be pine mires of medium fertility, and correspondigly KR, VIR, and RR were of poor fertility. Thus comparison to the preliminary results was enabled.

Table 10. Comparison between twinspan edaphic grouping of the sample plot material and peatland site type groups. Values are numbers of sample plots in respective group, values within brackets are control plots allocated on the basis of 1974 soil data.

Peatland site type	Site quality index	Twinspan edaphic group				
		00	01	100	101	11
		Fertile sites			Poor sites	
Hardwood-spruce mires						
KgK	2.6	. .	. .	. .	. .	(1)
PK	2.6	(1)	. .	. .	. .	. .
PsK	2.0	(1)	. .	. .	. .	. .
Medium pine mires						
VLR	3.2	. .	. .	. .	5	3
RLR	2.4	. .	. .	. .	. .	(1)
VSR	2.0	13(1)	1(1)	. .	2	. .
PsR	1.8	(2)	7	8(1)	16(1)	1
LkR	1.2	4	2	. .	(2)	2
Poor pine mires						
KR	1.4	. .	7	. .	. .	1
IR	1.2	. .	. .	4	1	. .
RaR	1.0	. .	. .	. .	9	7

The order of TS groups in Table 10 can be assumed to reflect a complex gradient of declining fertility (a complex of the NP and acidity gradients identified in the DCA ordination). On this basis, if the original peatland site type had been correctly assessed, then the plots should concentrate along the diagonal of the matrix. With some exceptions, to be discussed in ch. 51., this seem to be the case.

42. Sample tree properties of the edaphic groups

Reliable pre-drainage (1964) stand volume or stand increment data for comparison of tree stands among the edaphic TS groups can not be calculated. As a coarse measure of between group differences, average sample tree volumes 1964 are given as frequency distributions (Fig. 14). With the exception of group 100, which consists of sample plots with small trees, the variation within the edaphic groups is substantial and the distribution highly skewed. The high average volume of sample trees allocated to the group 11 does not imply closed stands with high volume on these nutrient poor sites; as in this case, a relatively dry site of low fertility may support a sparse stand with few large trees (Heikurainen 1971).

As a measure of potential production, sample tree mean basal area increment per cents for the edaphic groups during the growth period prior to fertilization (1965–69) are presented in Table 11. For comparison, the experimental fields are also classified into groups according to peatland site type and site quality index (Seppälä & Westman 1976, Härkönen 1982). Between fertility group differences were tested separately for each classification by analysis of variance and analysis of co-variance (P1V, BMDP 1983). In the

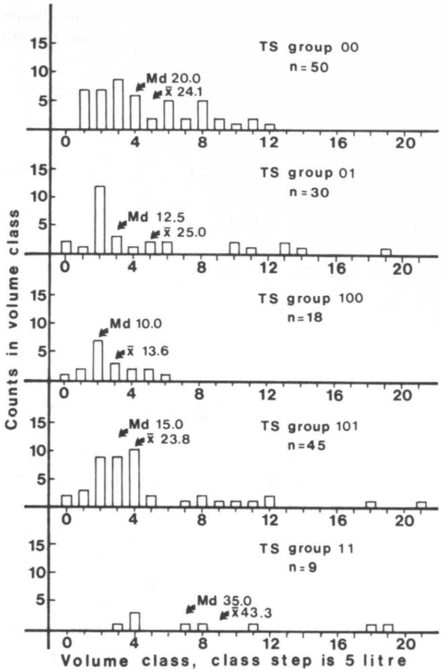

Figure 14. Volume of sample plot average tree before drainage and fertilization (1964). Volume frequencies are given separartely for each twinspan edaphic group.

analysis of co-variance the influence of sample tree volyme upon basal area increment per cent was eliminated by using the logarithm ($\log_{10}$) transformed sample tree basal area (1964) as a co-variate. Besides with non-adjusted means, co-variate adjusted means are given in Table 11.

With the exception of groups 01 and 100, the trend in basal area increment per cent along the fertility gradient becomes consistent in the three separate groupings after correcting the means with the co-variate. However, the classification based on the TS edaphic groups is more detailed than the two other classifications. Pairwise comparisons between these groups show that, with respect to basal area increment per cent, the two most fertile groups (00 and 01) clearly differ from the two least fertile groups (101 and 11).

The high basal area increment per cent on plots allocated to group 100 is unexpected when considering the intermediate edaphic properties characteristic for this group. Most of the plots in the group are from two adjoining experimental fields (14 and 15), the peatland site type of which are either *Carex globularis* pine swamp or Spruce-pine swamp. In addition to the high accumulative temperature sum at the site (highest in the material) both experimental fields slope towards the south resulting in a more favourable local climate. Further the relatively shallow peat deposit (0.5–0.7 m) is influenced by spring water. Experimental fields 14 and 15 were drained in 1968 and under the particular environmental conditions described the small sample trees (Fig. 14), may have markedly increased diameter increment during the growth period 1965–69. In the other edaphic groups drainage age of the sites varies more randomly. Despite the apparent contradiction between stand growth data and edaphic properties, group 100 will be treated together with the sites of poor fertility (TS groups 101 and 11) in the following estimation of the fertilization effect.

43. Sample plot stand increment

431. The effect of drainage upon increment

The influence of drainage upon increment is estimated from the non-fertilized control plot data. Non-linear models (eq. 2) were fitted to describe the relationship between the pre-drainage (1964) sample tree basal area and the post-drainage basal area increment per cent during the growth periods 1965–69, 1970–74 and 1975–81 (Figures 15 to 19). The regressions were formed separately for fertile sites (TS groups 00, 01) and sites poor in fertility (TS groups 100, 101 and 11), and for three drainage age classes (1965–66, 1967–68 and 1969–70).

The tree size – growth rate relationship is, however, complicated on recently drained peatlands. On these sites small trees may be physiologically old and consequently, after drainage, incapable to the increase in growth rate which is indicated by their size. The increment per cent for big trees is always low in comparison to that of small trees. Thus, the largest deviations between observed and predicted values are found for the small trees with low basal area. In some models the independent variable (basal area at 1964) has a maximum below 60–100 cm^2, while the highest observations in other models reach 400–500 cm^2. This difference in basal area variation is also reflected by the intercept and slope coefficient of the models. Except for the sites drained in 1967–68, the mean square error of the models also increases with increasing time lag between predictive and predicted variable. Because of these features it is evident that the regressions (Figures 15 to 19) are not a suitable basis for statistical comparison between the fertility groups and drainage age classes. However, within group comparisons between sequential curves will show the effect of drainage upon sample tree growth.

The influence of drainage on sample tree increment is first seen on the sites were drainage has been effective the longest period of time (Fig. 15). On the fertile sites drained 1965–66, basal area growth indicate that drainage have reached its full effect already during the period 1970–74. The curve for the growth period 1975–81 is of the same form and on the same level as the curve describing basal area increment per cent during 1970–74. On the nutrient poor sites in the same drainage age class, the small trees react first to drainage but not until the last growth period (1975–81) also the big trees have benefited from the improved conditions. The same trends are seen for Norway spruce and birch (Fig. 18). The difference in increment per cent between Norway spruce and Scots pine on equal sites may be due to the slower reaction of spruce to drainage (Heikurainen & Kuusela 1962), or because these sites actually are better suited to Scots pine.

Table 11. Sample tree basal area adjusted and non-adjusted mean annual basal area increment per cent 1965–69 in twinspan edaphic groups (present study), peatland site type groups (Seppälä & Westman 1976), and site quality index groups (Härkönen 1982). Bars indicate significant differences at 5 % risk level.

Grouping	Number of plots	Mean basal area increment per cent 1965–69 adjusted mean	non-adjusted mean
Twinspan edaphic group			
00	50	3.09	3.02
01	30	2.89	2.92
100	18	3.05	3.41
101	45	2.52	2.55
11	9	2.28	1.66
F-statistic		4.41**	4.93***
Peatland site type group			
hardwood-spruce mires	16	3.02	2.79
medium pine mires	104	2.86	2.92
poor pine mires	32	2.63	2.53
F-statistic		co-variance model could not be applied	n.s.
Site quality index group			
≥ 2	48	3.15	2.64
< 2	104	2.68	2.91
F-statistic		9.80**	n.s.

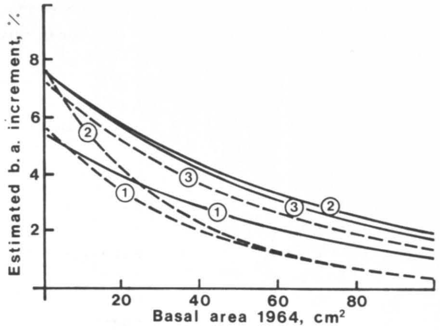

Figure 15. Relationship between Scots pine 1964 sample tree basal area and corresponding mean basal area increment per cent on non-fertilized control plots during three growth periods (1 = 1965–69, 2 = 1970–74, 3 = 1975–81) on sites drained 1965–66. Solid lines denote the fertile site group (TS edaphic groups 00 and 01) and broken lines denote the nutrient poor site group (TS edaphic groups 100, 101 and 11).

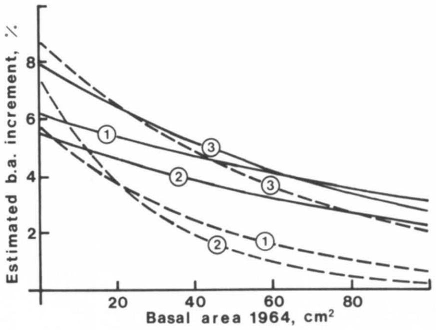

Figure 16. Relationship between Scots pine 1964 sample tree basal area and corresponding mean basal area increment per cent on non-fertilized control plots during three growth periods (1 = 1965–69, 2 = 1970–74, 3=1975–81) on sites drained 1967–68. Solid lines denote the fertile site group (TS edaphic groups 00 and 01) and broken lines denote the nutrient poor site group (TS edaphic groups 100, 101 and 11).

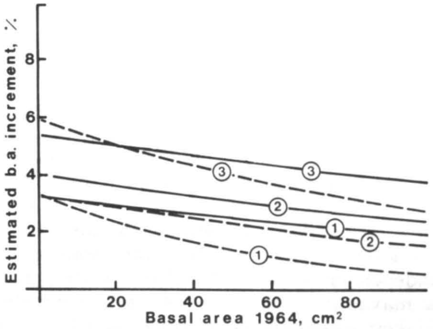

Figure 17. Relationship between Scots pine 1964 sample tree basal area and corresponding mean basal area increment per cent on non-fertilized control plots during three growth periods (1 = 1965–69, 2 = 1970–74, 3=1975–81) on sites drained 1969–70. Solid lines denote the fertile site group (TS edaphic groups 00 and 01) and broken lines denote the nutrient poor site group (TS edaphic groups 100, 101 and 11).

On the most recently drained sites (Fig. 17), basal area increment per cent successively increases during the three sequential growth periods. The increase in growth per cent is relatively uniform over the entire basal area range, that is the particular capacity of small, physiologically reactive trees to fast growth reactions after drainage cannot be seen. The reason is the strong influence of the large trees upon the form and level of the regression curves. Within this drainage age class maximum sample tree basal area were 360 cm^2 and 460 cm^2 on the fertile and nutrient poor sites, respectively.

On the sites drained 1967–68 (Figures 16 and 19) the change in increment is confusing in comparison to the findings from the younger and older drainage age classes. While the curves describing basal area increment per cent during the period 1975–81 clearly indicate increased growth, it seems as if the immediate effect of drainage (growth period 1970–74) is neglible; on the fertile sites, the increment per cent is even lower than prior to drainage. Short-term climatic fluctuations do not explain this result. According to Tiihonen (1979), growth indices for pine on upland sites in north Finland during the period 1965–70 are clearly below, and from 1970 onward, slightly above long-term mean level. Thus one would expect increasingly improved growth during the two post-fertilization periods instead of a growth depression. Local climatic variation is also excluded as a cause, as the sites in question are distributed from the northern most to the southern most site. However, one feature common to the sites drained 1967–68 is the shallow peat layer (Table 1). It is thus possible that the influence of drainage on these sites has been faster and more effective than on sites with a deeper peat layer, and root activity temporarily becomes depressed because of competition from soil organisms for available nutrients (Karsisto 1976). Comparable trends are not observed in the curves for the other drainage age classes. As was noted on sites drained 1967–68, the regression for the growth period 1965–69 had the highest mean square error, and the accuracy of the models increased along the time series.

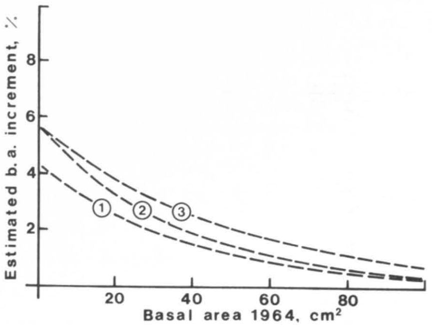

Figure 18. Relationship between Norway spruce 1964 sample tree basal area and corresponding mean basal area increment per cent on non-fertilized control plots during three growth periods (1 = 1965–69, 2 = 1970–74, 3 = 1975–81) in the nutrient poor site group (TS edaphic groups 100, 101 and 11), and sites drained 1965–66.

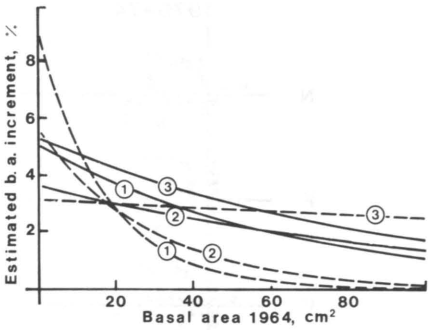

Figure 19. Relationship between Norway spruce 1964 sample tree basal area and corresponding mean basal area increment per cent on non-fertilized control plots during three growth periods (1 = 1965–69, 2 = 1970–74, 3 = 1975–81) on sites drained 1967–68. Solid lines denote the fertile site group (TS edaphic groups 00 and 01) and broken lines denote the nutrient poor site group (TS edaphic groups 100, 101 and 11).

The strong positive response to drainage found on the sites of poor fertility drained 1967–68 is a result of the favourable growth development on the experimental fields 14 and 15.

432. The effect of NPK upon increment

The effect of fertilization upon growth is presented (Fig. 20) as sample plot estimates of changes in basal area increment per cent (eq. 4). The estimates are given separately for each fertilization treatment, site fertility group (TS groups 00 and 01, and groups 100, 101 and 11), and two growth periods 1970–74 and 1975–81. Significance testing of the corresponding group means are given (Table 12).

During the growth period immediately after fertilization (1970–74) the difference in growth response between the two fertility groups is clear (Table 12). Except for the PK and NPK treatments, the effect of fertilization on the nutrient poor sites is more than twice as high as on the fertile sites. However, pairwise comparison of each fertilizer treatment between the fertility groups show significant differences only for the NP treatment. On the sites low in fertility all treatments except K have, in comparison to the control plots, significantly increased growth. The strongest fertilizer response was evoked by the NP treatment, which statistically differs from all other treatments. On the fertile sites, only the

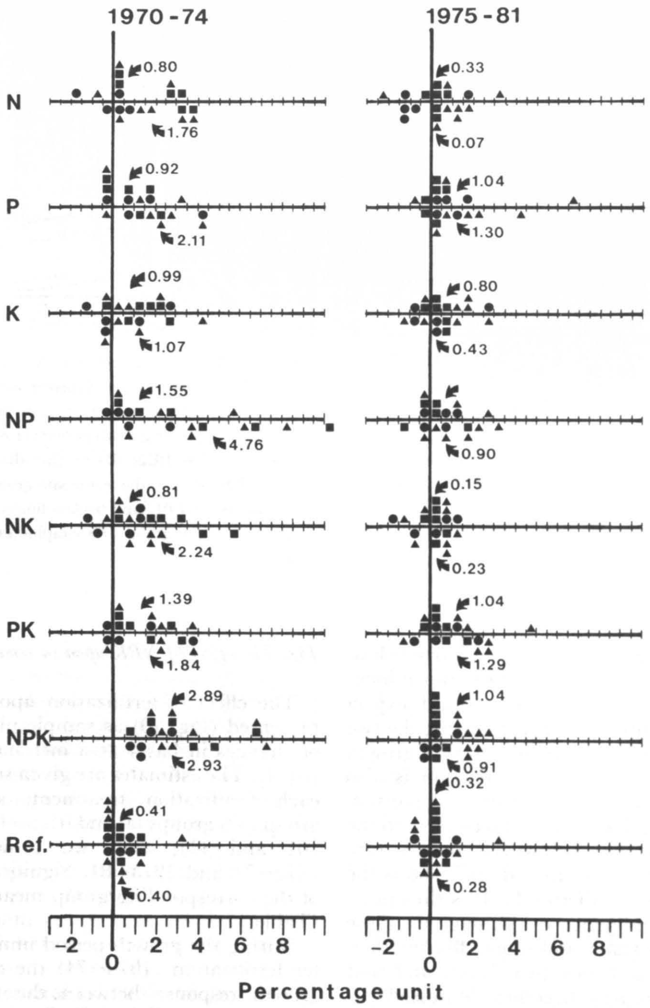

Figure 20. Effect of fertilizer treatment on sample plot mean basal area increment per cent. Each symbol (● = sites drained 1965–66, ■ = sites drained 1967–68, ▲ = sites drained 1969–70) denote the sample plot mean change in increment per cent during the two growth periods after fertilization (1970–74 and 1975–81). Fertile sites (TS edaphic groups 00 and 01) are above scale line, and poor sites (TS edaphic groups 100, 101 and 11) are below scale line.

Table 12. Effect of fertilization upon basal area increment in two site fertility groups (TS groups 00 and 01, and TS groups 100, 101 and 11) during two growth periods. Values given are based on equation (4) and expressed as percentage units. Bars indicate significant differences at 5 % risk level.

Fertilizer treatment	Estimates of change in basal area increment per cent			
	1970–74		1975–81	
	fertile	poor	fertile	poor
N	0.80	1.76	0.33	0.07
P	0.92	2.11	1.04	1.30
K	0.99	1.07	0.80	0.43
NP	1.55	4.76	0.64	0.90
NK	0.81	2.24	0.15	0.23
PK	1.39	1.84	1.04	1.29
NPK	2.89	2.93	1.04	0.91
control	0.41	0.40	0.32	0.28
F-statistic between:				
fertility groups	10.99***		n.s.	
treatments	5.91***		2.13*	

NPK treatment gives a statistically significant increase in increment. The growth on the NPK plots not only differs from the control plot but also from growth on the plots receiving the N, P, K and NK treatments. It is also noted that while the NP treatment on the fertile sites has a high estimated fertilizer response, it is neither significantly different from the increment on the control plots or any of the other fertilizer treatments.

During the later growth period, 1975–81, only the NPK and NK treatments in the fertile plot group, and P and N treatments in the nutrient poor plot group differ significantly (Table 12). The plot estimates (Fig. 20) and ranking of the means in Table 12 would indicate a prolonged growth response to the P treatment. On the poor sites all four treatments involving P are ranked first before other treatment means. On the fertile sites the trend is not so consistent, but the PK and NPK treatments also indicate a positive effect of P fertilization. The strong response of the P treatment on the fertile sites is partly caused by the particularly positive growth reaction on experimental field 23.

The effect of the easily soluble N fertilizer has levelled off during the second growth period (Table 12). Generally, the estimated change in growth evoked by N, either alone or in combination, in both fertility groups does not differ from the non-fertilized control plot level (Fig. 20). On the less fertile sites, the N treatment even tends to depress growth. This tendency may also be seen from the growth development on the NP and NK treatment plots. During the second period the particularly strong initial response to NP has changed to an intermediate growth response, which contradicts the generally considered long lasting positive effect of the P treatment. The development on the NK plots also seems less favourable than could be expected on the basis of the K and PK tratments. The means for the two growth periods are, however, calculated differently. The first period is a five year period while the second period is seven years. This difference in the length of periods particularly influences the interpretation of the nitrogen effect, which generally is considered to last some 5–10 years (e.g. Paavilainen 1979b).

As was noted in ch. 431. the increment on the control plots increased continuously in the youngest drainage age class during the three growth periods, while in the oldest age class the drainage induced change in increment had almost stabilized by the time of fertilization (1970–74). This difference in the effect of drainage related to the age of drainage is a large source of variation when examining the response to fertilization. During both growth periods (1970–74 and 1975–81) there are significant differences in fertilizer response between the drainage age groups (Table 13).

For the period 1970–74, when the fertilization effect should be the most pronounced, the response to fertilizer is the smallest on sites drained 1965–66 (Table 13). This trend is particularly clear for N fertilizer, alone or in combination; within each treatment the estimated effects differ significantly or almost significantly between the oldest drainage age class and either of the two younger classes. On sites drained 1965–66 P, alone or in any combination, gave the best result.

Generally, it seems that during the period 1970–74 the best results from fertilization are obtained on sample plots drained 1967–68, where all treatments involving N significantly differ from the control level (Table 13). On the sites drained 1969–70 the effect of NP and NPK treatments was equally strong while N and NK treatments only tended to increase growth. The result is in accordance with the trend in basal area increment indicating a temporary depression of growth, which was assumed to be the result of microbiological immobilisation of nitrogen and phosphorus (ch. 431.).

During the later growth period (1975–81), when the N fertilization effect had levelled off (Table 12), the trend towards a prolonged P effect is clearly seen in the most recently drained sites only (Table 13). Within the two older drainage age classes (1965–66 and 1967–68), the PK treatment particularly seem more advantageous than others. However, there are no statistically significant differences among the fertilizer treatments in these two drainage age classes.

The estimation of fertilizer effect is dependent upon the regression describing the non-fertilized basal area increment per cent. It is essential that the distribution of sample tree basal area on the treated plots do not differ from the distribution of the control plots. Extending the regressions beyond the variation width of the control plot material may strongly lower the reliability of the fertilized sample plot estimates. Generally, the distributions do coincide, but on the fertile sites drained 1965–66 and 1967–68 and on the nutrient poor sites drained 1969–70, the right-hand tails of the skewed basal area distributions of the fertilized plots are somewhat underrepresented in the corresponding control plot material. Moreover, on the control plots where there has been no fertilizer, the difference between predicted and observed basal area increment should be zero. The control plot mean estimates, however, range between 0.23 and 0.49 (Tables 12 and 13), i.e. the basal area increment per cent on the control plots is underestimated and, consequently, the effect of fertilization overestimated. The larger deviations from zero by the group of fertile sites (Table 12) is the result of the high increments of plots from experimental field 23. However, as the estimates for the control plots show no systematic clustering to any particular drainage age (Fig. 20), the bias is similar for each drainage age model.

Table 13. Effect of fertilization upon basal area increment during two growth periods in three drainage age classes. Values are based on equation (4) and expressed as percentage units. Bars indicate significant differences at 5 % risk level.

Fertilizer treatment	Estimates of change in basal area increment per cent					
	1970–74			1975–81		
	1965–66	1967–68	1969–70	1965–66	1967–68	1969–70
N	–0.21	2.28	1.53	–0.69	0.27	0.69
P	1.48	0.89	1.93	0.96	0.19	2.02
K	0.37	1.48	1.10	0.41	0.41	0.91
NP	0.81	4.37	3.92	0.43	0.31	1.34
NK	0.21	2.84	1.09	–0.06	0.27	0.27
PK	1.06	1.47	2.04	0.74	0.61	1.84
NPK	1.48	3.28	3.52	0.34	0.33	1.88
control	0.26	0.43	0.49	0.33	0.23	0.33
F-statistic between:						
drainage age classes		9.58***			10.22***	
treatments		5.05***			2.10*	

To test the validity of the conclusions drawn from the estimated fertilization effect (Fig. 20, Tables 12 and 13), a parallel testing of the development in basal area increment was undertaken. The use of the logarithm ($\log_{10}$) transformed initial (1964) basal area as a co-variate in an analysis of co-variance with site fertility and fertilization treatment as class variables, give results which generally coincide with those presented above. The analysis of co-variance was, however, clearly less sensitive in distinguishing group differences.

To compare the results from the preliminary surveys of the fertilization experiment (Seppälä and Westman 1976, Härkönen 1982) with those results obtained after reclassification of the sample plot material according to the edaphic properties of the sites, the sample plot material was classified into peatland site type and site quality groups (Tables 14 and 15), and differences between treatments were investigated with analysis of co-variance. During the growth period 1970–74 no differences in response pattern between the different fertility groups could be found and, irrespective of classification method, NP and NPK were outstandingly the most efficient treatments. During the later growth period (1975–81) the levelling of the fertilization effect seemed complete.

So far, the evaluation of the effect of drainage and fertilization treatments has been based on sample tree basal area growth. In order to describe the fertilizer effect on the development of the sample plot stand, the volume increment ($m^3 \cdot ha^{-1}$) is presented in Tables 16 and 17, and will be used as a basis for evaluating the overall amelioration effect in the concluding discussion (ch. 51.).

Table 14. Basal area increment per cent during two growth periods in two peatland site type groups (Seppälä & Westman 1974). Hardwood-spruce mires are excluded from the analysis. Bars indicate significant differences at 5 % risk level.

Fertilizer treatment	Basal area increment per cent			
	1970–74		1975–81	
	medium pine mires [1]	poor pine mires [2]	medium pine mires	poor pine mires
N	4.27	4.21	4.62	4.11
P	4.68	4.13	5.70	5.32
K	4.25	3.62	5.40	4.02
NP	6.43	5.85	5.41	5.00
NK	4.33	5.31	4.31	4.38
PK	4.89	4.05	5.69	5.32
NPK	6.21	6.18	5.59	5.66
control	3.79	2.23	4.75	4.00
F-statistic between:				
site type groups	n.s.		n.s.	
treatments	4.85***		n.s.	

[1] VLR, RLR, VSR, PsR, LkR

[2] IR, KR, RaR

Table 15. Basal area increment per cent during two growth periods in two site quality groups (Härkönen 1982). Bars indicate significant differences at 5 % risk level.

Fertilizer treatment	Basal area increment per cent			
	1970–74		1975–81	
	SQI ≥ 2.0 1)	SQI < 2.0 2)	SQI ≥ 2.0	SQI < 2.0
N	4.12	4.10	4.90	4.17
P	3.99	4.46	4.87	5.60
K	4.74	3.65	5.64	4.57
NP	5.75	6.29	5.19	5.18
NK	4.72	4.45	4.84	4.39
PK	4.22	4.60	4.71	5.62
NPK	5.55	6.10	5.63	5.31
control	3.79	3.15	4.58	4.43
F-statistic between:				
SQI groups	n.s.		n.s.	
treatments	4.33***		n.s.	

1) PK, VLR, VSR
2) IR, KR, LkR, PsR, RaR

Table 16. Sample plot stand volume increment during three growth periods (drainage 1965–70 and fertilization in June 1970). Bars indicate significant differences at 5 % risk level.

Fertilizer treatment	Stand volume increment, $m^3 \cdot ha^{-1} \cdot period^{-1}$		
	1965–69	1970–74	1975–81
N	1.9±0.3	3.8±0.5	9.1±1.1
P	2.5±0.5	4.3±0.7	11.8±1.3
K	2.2±0.4	3.4±0.5	9.9±1.3
NP	2.3±0.4	5.5±0.6	12.7±1.6
NK	2.2±0.3	4.7±0.6	10.1±1.1
PK	1.9±0.3	3.6±0.5	9.8±1.1
NPK	2.3±0.4	6.1±0.6	13.3±1.2
control	2.3±0.4	3.1±0.5	8.5±1.0
F-statistic between treatments	n.s.	3.59***	2.18*

433. *The effect of NPK upon needle nutrient contents*

In ch. 412. it was noted that the manganese content of the peat is reflected in the manganese content of the needles, and that needle contents were negatively correlated to height increment. For the other nutrients, the relationships between soil and needle contents and height increment are not so clear. The highest significant correlations for needle contents and height increment are for phosphorus ($r_{nP, hi}$ = 0.403***) and nitrogen ($r_{nN, hi}$ = 0.315**), the nutrients which have also significantly increased sample tree growth when added as fertilizers (ch. 432.). The postive influence of these nutrients upon growth is also seen from height increment data in Table 18. For potassium, the needle content and height increment correlation is clearly smaller ($r_{nK, hi}$ = 0.213*).

Table 17. Estimated change in sample plot stand volume increment due to fertilizer treatment during two growth periods and overall during the experimental period (drainage 1965–70 and fertilization in June 1970). Bars indicate significant differences at 5 % risk level.

Fertilizer treatment	Estimated change in volume increment, $m^3 \cdot ha^{-1} \cdot period^{-1}$		
	1970–74	1975–81	1970–81
N	0.58±0.28	0.22±0.38	0.79±0.57
P	0.82±0.21	1.44±0.43	2.26±0.53
K	0.37±0.24	0.98±0.47	1.35±0.66
NP	1.79±0.33	1.45±0.60	3.24±0.69
NK	1.21±0.27	0.61±0.39	1.83±0.55
PK	0.68±0.17	1.32±0.39	2.00±0.54
NPK	2.21±0.28	2.07±0.51	4.28±0.65
control	0.13±0.07	0.16±0.27	0.29±0.33
F-statistic between treatments	9.17***	2.34*	5.22***

The influence of N, P and K fertilization upon needle contents is evaluated by grouping the material into fertilized and non-fertilized plots. Group mean values are presented in Table 18 and significant differences between fertilized and non-fertilized plots, and between edaphic groups, are indicated.

Needle nitrogen contents do not differ between fertilized and non-fertilized plots. However, the height increment differences between TS group 00 and the less fertile groups (Table 18) are clearly larger in the non-fertilized plot group than in the fertilized plot group. The positive effect of nitrogen fertilization upon growth during the period 1970–74 has thus decreased the differences in increment within the site continuum. The long-term effect of phosphorus fertilization on sample tree growth (ch. 432.) is also reflected by needle contents of phosphorus. With the exception of TS group 100, the P content is significantly higher in needles from plots receiving P fertilizer. This trend is particularly clear within the fertile site group (TS groups 00 and 01), where P fertilization also significantly increased height growth. Although potassium was found to have little influence upon sample tree growth (ch. 432. and Table 18) and potassium in peat is easily mobile, it is clear that fertilization with the easily soluble K has given a long-term increase in needle potassium content. The differences are, however, significant only within TS group 101 but almost significant within group 01.

Table 18. Needle nutrient contents, relative estimates of nutrient consumption of sample tree, and height increment for fertilized and non-fertilized treatments in the twinspan edaphic groups. Bars indicate significant differences at 5 % risk level.

Twinspan edaphic group	Nutrients in needles mg · g^{-1} dry matter		relative estimates of consumption		Height increment 1975–81 cm · a^{-1}	
	fertilized plots	non-fertilized plots	fertilized plots	non-fertilized plots	fertilized plots	non-fertilized plots
			nitrogen			
00	13.4±1.8	13.7±0.7	0.53±0.07	0.56±0.07	17.6±2.0	17.7±1.8
01	11.5±0.4	11.2±0.3	0.31±0.04	0.26±0.03	11.9±1.9	10.0±1.0
100	12.7±0.9	12.2±0.7	0.39±0.08	0.31±0.03	13.1±2.4	11.0±0.7
101	10.9±0.5	11.4±0.6	0.32±0.04	0.29±0.03	12.7±1.3	10.8±0.8
11	10.7±0.4	10.1±1.3	0.26±0.05	0.19±0.06	10.7±2.1	7.8±1.7
F-statistic between:						
treatments	n.s.		n.s.		n.s.	
TS groups	9.67***		5.16***		6.74***	
			phosphorus			
00	15.7±0.08	1.24±0.06	0.61±0.08	0.35±0.05	20.8±2.0	15.1±1.4
01	1.34±0.05	1.08±0.10	0.35±0.05	0.16±0.03	13.1±1.4	8.0±1.2
100	1.38±0.05	1.36±0.06	0.29±0.04	0.29±0.03	11.6±1.4	11.5±1.1
101	1.41±0.03	1.21±0.03	0.32±0.04	0.26±0.03	12.3±1.2	11.6±1.2
11	1.41±0.08	1.13±0.05	0.29±0.05	0.15±0.04	11.1±2.0	7.4±1.6
F-statistic between:						
treatments	17.94***		38.29***		9.21**	
TS groups	9.67***		n.s.		9.00***	
			potassium			
00	3.85±0.20	3.59±0.21	0.44±0.08	0.42±0.04	17.3±2.3	18.0±1.5
01	3.52±0.14	2.99±0.21	0.29±0.04	0.18±0.03	12.3±1.5	9.2±1.5
100	4.49±0.39	3.78±0.22	0.37±0.06	0.27±0.03	12.5±1.3	11.0±1.1
101	3.84±0.09	3.50±0.11	0.29±0.03	0.29±0.04	11.4±1.2	12.5±1.3
11	3.65±0.26	3.42±0.12	0.23±0.03	0.20±0.04	9.9±1.9	9.3±1.8
F-statistic between:						
treatments	n.s.		9.32**		n.s.	
TS groups	5.46***		5.33***		6.59***	

5. DISCUSSION

51. The edaphic grouping

Using measured edaphic properties and the multivariate classification methods: decorana and twinspan (Hill 1979a and 1979b) and discriminant analysis (P7M, BMDP 1983), the sample plot material was objectively grouped into five edaphic groups. In the evaluation of the fertilization experiment, the sample plots were then pooled into two fertility groups: fertile (TS groups 00 and 01) and poor (TS groups 100, 101 and 11) sites.

The use of the 1981 soil sample material, which includes non-fertilized and fertilized sample plots, in establishing the edaphic sample plot groups and then approximating the situation at the time of drainage can be criticized. However, the most important classifying variables, soil acidity and related properties are not affected by NPK fertilization. Also the influence of 100 kg · ha^{-1} N fertilization upon the total content of nitrogen in the peat (some 3500 kg N · ha^{-1} in the 30 cm top layer, Table 2), is certainly minor eleven years after fertilization. The effect of P and K fertilization on the 1981 soil sample data would be much more pronounced as the fertilizer amount is relatively high in comparison to the natural total contents of the peat. From Appendix 2 is seen that more often than not sample plots from one experimental field are classified into the same edaphic TS group. In cases when plots are separated from the parent experimental field, the fertilizer treatment received by the plot does not seem to be the reason for the splitting. Moreover, the changes in soil properties since drainage seem minor. There are no significant differences in edaphic properties between the same control plots when sampled in 1974 and 1981 (ch. 411.). The slow drainage effect is also indicated by the slow development of surface vegetation on the sites. During the 1981 field work it was evident that the ground vegetation on the sites had remained nearly unchanged during the 11 to 17 years since drainage.

The soil sampling in 1974 and 1981 represent two different peatland site type distributions (ch. 411.). Although repeated samplings from the same plots gave similar results, the 1974 material covers the entire range of experimental fields and thus comprises a more extended edaphic gradient than the 1981 sample material. Thus for example the sample plots excluded from the 1981 sampling on the basis of tree stand species composition or the depth of the peat layer (plots enclosed in brackets in Table 10) would be allocated to the upper end of the trophic gradient recognized in the decorana analysis. Two of the three hardwood-spruce mires sampled only in 1974 are also in accord with their assumed fertility allocated to the TS group 00. A third plot, a paludified *Vaccinium myrtillus* spruce forest is classified into the poor TS group 11. The mean peat depth at this site is only 0.2 m, indicating that the site is transitional between upland and peatland sites, and the measured edaphic properties are strongly affected by the underlying mineral soil. As there is only one observation from each of these experimental fields within field variation can not be evaluated, and the rest of sample plots on these fields are classified according to the control plots. The edaphic differences between other control plots sampled in 1974 only and the 1981 sample plot material are less pronounced.

The relationship between the TS edaphic groups and the field classification into peatland site types applied in the preliminary survey is given in Table 10. There is most agreement in the case of the tall-sedge pine fens, with the majority of the sample plots allocated into groups 00 and 01. The field classification of the other sites is less successful in reflecting the edaphic properties of the sample plots. The *Carex globularis* pine swamps and the low sedge *Sphagnum papillosum* pine fens show substantial variation, both within and between sites, with sample plots spread over the whole range of TS groups. The two most fertile pine mires, a eutrophic pine fen and a eutrophic *Sphagnum fuscum* rich pine fen, are allocated into the poor TS groups 100 and 11 on the basis of their edaphic properties.

To conclude, it is clear that the accuracy of the field classification of the experimental fields was inaccurate, and has affected the interpretation of the results from the preliminary survey 1974 (Seppälä & Westman 1976). Particularly the actual low fertility of the sites classified as eutrophic pine fens (Table 10) may have contributed to the good initial response to nitrogen amongst site types generally considered not to require nitrogen fertilization. The bias is, however, contradicted by the relatively high fertility found among experimental fields classified as poor pine mires in Seppälä and Westman's (1976) report, i.e. the *Carex globularis* pine swamps and low sedge *Sphagnum papillosum* pine fens which in the edaphic classification in several cases are allocated to the fertile plot group (Table 10). The change of order between the spruce-pine swamp (KR) and low sedge *Sphagnum papillosum* pine fen (LkR) in the trophic site type continuum in the preliminary survey (Seppälä & Westman 1976) was also less successful. In the edaphic TS classification most of the sample plots from the spruce-pine swamp (KR) experimental field are ranked to be of higher fertility than plots originally classified as *Sphagnum papillosum* pine fens (LkR). Keltikangas et al. (1986) also recently concluded that the production potential of particularly the low sedge *Sphagnum papillosum* pine fens in north Finland has been overestimated. The peatland site type classification is an average for the experimental field, while the edaphic properties relate to the sample plot. The regrouping of the material on the basis of the edaphic properties using ordination and classification techniques is, therefore, more detailed and exact.

52. The fertilization experiment

During the first growth period (1970–74), all fertilization treatments tend to increase sample tree growth. However, on the fertile sites (TS groups 00 and 01) only NPK gave a significant effect while on the sites of low fertility (i.e. TS groups 100, 101 and 11), N and P separately and, particularly, in combination significantly increased growth. There is a clear difference between the fertile and poor sites in their response to fertilization. On the nutrient poor sites, which are low in peat nitrogen and phosphorus (Table 7), the increase in growth is significantly higher after fertilization than on the fertile sites. This trend is consistent within most treatments but only significant for the NP treatment.

The overall favourable effect of N and P upon growth is in agreement with the preliminary results of the experiment (Seppälä & Westman 1976). However, after reclassifying the sample plots into fertile and nutrient poor plot groups this effect is less pronounced amongst the fertile plots than the preliminary survey indicates. The results also confirm the impression that nitrogen and phosphorus mineralization is retarded by the prevailing climatic conditions, even on relatively fertile sites. In young pine stands planted on open fens and bogs in middle Finland, Kaunisto (1982, 1984) reported that N application is not required when the total nitrogen concentration in peat varies between 1.3 and 1.4 per cent, and NPK fertilization was even deleterious in cases where the peat nitrogen content was 1.9 per cent and above. In the present material from naturally pine growing sites, the mean nitrogen content (17.0–21.6 mg $N \cdot g^{-1}$) in the peat from the fertile sites (TS groups 00 and 01, Table 7), where N fertilizer had a positive effect upon growth, is far above Kaunisto's critical values.

The positive effect of nitrogen is, however, shortlasting. During the second growth period there is even an indication of a potential growth retarding effect. A fertilization induced nitrogen demand is also in accord with Paavilainen's (1978, 1984) results, according to which nitrogen does not become important until later in the stand development, and particularly in connection with refertilization. Needle analysis data (Table 18) also show that needle nitrogen contents of sample trees in 1981 were below the critical limit, except for TS group 00, and there is a need for nitrogen fertilization (cf. Paarlahti et al. 1971, Paavilainen 1979b, 1980, 1984, Sippola et al. 1985).

During the second growth period (1975–81) only a few fertilization treatments significantly differ within the fertility groups, indicating a prolonged influence of phosphorus. The lasting effect of the slow release phosphorus fertilizer (rock phosphate) was to be expected. Mean height increment during the growth period 1975–81 and the phosphorus content in needles collected eleven years after fertilization both reflect the beneficial effect of P (Table 18).

The unimportance of K with respect to stand increment appears to contradict the findings of other studes (e.g. Paavilainen & Simpanen 1975, Paavilainen 1978, 1979b). The studies cited, however, refer to experiments conducted on sites drained decades prior to fertilization when both the stand demand and the peat supply of nutrients are different than in the present study. In the present material, mineral soil in the shallow peat of several of the experimental fields (Table 1) certainly influences on the potassium economy of the sites. However, the tendency for a positive growth response to K fertilization on the fertile sites (particularly when applied jointly with NP, ch. 432.) can be interpreted as an indication of future potassium deficiency. The volumetric potassium content in the peat is not significantly different among the five TS edaphic groups (Table 7), and on the fertile sites where changes in stand growth are fast, substantial amounts of potassium may already have been taken up from the peat and fixed in the standing biomass. In the fertile site TS edaphic groups (00 and 01) the relative estimate of potassium consumption is significantly the higher in TS group 00 (Tables 8 and 18). In the material, the mean needle content of potassium 1981 is also below limits considered as critical for normal development of pine on mire sites (e.g. Paarlahti et al. 1971, Paavilainen 1979b, 1980, 1984, Sippola et al. 1985).

Although there is only a weak measured effect of K upon growth, the K treatment clearly affects the nutrient balance of the sites as reflected by the tendency to increased needle K contents. When comparing fertilized and non-fertilized sample plots (Table 18), the K fertilization treatment tends to have a long-term influence upon needle potassium content. Thus a small fertilizer dose of this easily exchangeable and leachable nutrient is efficiently incorporated into the soil-vegetation system, and can be analytically traced even more than a decade after the fertilzer application. The unexpected increase in needle content of K corresponds to the long-term and delayed positive effects obtained with potassium fertilizers alone reported by Paavilainen and Simpanen (1975) and Paavilainen (1978).

To conclude, during each of the growth periods 1970–74 and 1975–81 the combined effect of drainage and fertilization doubled the volume increment (Table 16), but the annual volume growth was modest compared to growth on productive forest land, mean annual increment of which during a rotation period is >1.0 $m^3 \cdot ha^{-1}$. The differences in response to the fertilization treatments were also clear (Table 17). The best overall fertilizer response was gained with NPK and NP treatments, which during the eleven year research period gave on an average an additional 3–4 $m^3 \cdot ha^{-1}$. During the same period P and PK treatments gave approximately 2 $m^3 \cdot ha^{-1}$. Although individual sample trees on sites of low fertility strongly increased growth, the amelioration measures had little effect upon stand volume increment on the poorest sites. The low absolute amelioration effect must be related to the tree stand on the site and, in these climatic conditions, low stand volume is characteristic for poor sedge mires even after drainage (Keltikangas et al. 1986). Even on the best stocked sites, stand volume in 1981 did not exceed 65–70 $m^3 \cdot ha^{-1}$. Several of the plots had a standing volume of less than 10 $m^3 \cdot ha^{-1}$, and the stands on some plots were comparable to sapling stands (Appendix 1). Consequently great care should be taken when choosing sites for forestry production purposes in these climatic conditions. Soil analysis and the direct site production classifying method suggested in the present study may be an useful tool in this decision process.

6. SUMMARY

The present study is concerned with the estimation of the effect of NPK fertilizer treatments on the forest growth of some important peatland site types in north Finland. Some of the site types have generally been considered to have a satisfactory nitrogen economy and do not require N fertilizer. The results of an initial survey of the experiment in 1974, however, indicated a strong positive response to nitrogen, especially when combined with phosphorus, and the unimportance of potassium.

In connection with the second inventory in 1981 the question arose as to whether the unexpected nitrogen and phosphorus response was the result of inaccurate identification of the peatland site type at the time of drainage planning. It was thus decided to reclassify the sample plot material into fertility groups on the basis of edaphic properties before finally evaluating the effect of the fertilization (and drainage) treatments.

The research material consists of a NPK fertilization experiment on mires drained for forestry purposes 1–6 years before fertilization. Initially 27 experimental fields were laid out, but due to various land management measures only 23 and 19 experimental fields remained intact for the tree stand inventories in 1974 and 1981 respectively. Each field consists of at least eight sample plots with the following treatments N, P, K, NP, NK, PK, NPK, and one non-fertilized control plot. Fertilization with 100 kg · ha^{-1} nitrogen, 44 kg · ha^{-1} phosphorus and 83 kg · ha^{-1} potassium, given as ammonium nitrate with lime (26 % nitrogen), rock phosphate (14.5 % phosphorus) and potassium chloride (49 % potassium), respectively, was undertaken in June 1970.

On the basis of the data collected during the two inventories, sample tree parameters were calculated for the situation in 1964, 1969, 1974 and 1981. For each parameter mean annual per cent increment values were calculated as differences for the periods 1965–69, 1970–74 and 1975–81. The influence of drainage on non-fertilized sample tree growth was derived from models predicting relative basal area increment of sample trees. The influence of different fertilizer treatments upon sample tree increment was calculated as the difference between the observed mean annual basal area increment per cent and the predicted non-fertilized basal area increment per cent. The effect of fertilization upon volume growth was calculated on the basis of stand volume and the mean change in annual basal area increment per cent.

During both forest inventories, volumetric soil samples were collected. In 1974 samples were only taken from the non-fertilized control plots (25), whears in 1981 all plots with a peat deposit thicker than 0.3 m and a tree stand dominated by Scots pine were sampled (93). The 1981 sampling thus included both fertilized and non-fertilized plots. In association with the 1981 inventory, needle samples were also collected on those plots selected for soil sampling. From the soil samples overall descriptive variables: bulk density, ash content, pH, cation exchange capacity and base saturation, and total contents of macro- and micro-nutrients were determined. Ash and total contents of nutrients were also determined from the needle samples. The soil data was expressed on volumetric basis (mg·cm^{-3}).

Comparison of 1974 and 1981 soil data from the repeated samplings on twelve non-fertilized control plots sampled at both times, showed that there were no significant changes in soil properties between the two samplings. This indicates that, with respect to drainage, data from the both samplings can be used interchangeably in the same models.

To investigate edaphic gradients among the experimental fields a decorana (DCA) ordination of the sample plots using standardised 1981 soil data was computed. The standardised soil data had a range from 0 to 100, and a mean value of approximately 50. The results indicated that the sample plots were related to two main edaphic gradients which jointly reflected a trophic continuum. DCA axis 1, which was strongly correlated to nitrogen and phosphorus (and also iron) contents in the peat, was interpreted as the joint effect of the increasing degree of decomposition of the peat material and influence of underlying mineral matter. The second and the third DCA axes were both interpreted as acid-base gradients.

To objectively form edaphic sample plot groups a twinspan (TS) analysis was computed from the standardized 1981 soil data. Using the edaphic gradients identified in the DCA analysis, five edaphic groups were established. The edaphic properties of these groups were clearly reflected in sample tree properties. The highest values for needle nitrogen, phosphorus, potassium, calcium and magnesium were associated with the most fertile sample plots while the highest values for needle manganese contents were found for sample trees from the edaphic group that had distinctively the highest peat content of manganese.

To allocate plots not sampled in 1981 into TS edaphic groups a stepwise discriminant analysis was used in which the TS edaphic group of the sample plot was the class variable. A comparison between the basic TS classification and the subsequent allocation by the discriminant analysis showed that the latter could be used to allocate plots into TS edaphic groups with reasonable success. Out of 93 sample plots 80 were correctly allocated.

When comparing the overall peatland site type classification of the experimental fields and the TS edaphic groupings of individual sample plots, it became evident that within experimental field site type heterogeneity had affected the preliminary interpretations of the 1974 inventory. In some experimental fields the fertility of individual sample plots was clearly below the level indicated by the peatland site type assigned overall to that particular field, while on other fields, relatively high fertility was found among plots initially allocated to nutrient poor sites types.

In the evaluation of the amelioration measures the five TS edaphic groups were reduced to two fertility groups. The two most fertile TS edaphic groups were combined and the intermediate group was combined with the two nutrient poor groups. This simplification eliminated some of the anomalies arising from the missallocation of sample plots by the discriminant analysis. Sample tree basal area increment per cent data was grouped according to these fertility groups and three drainage age classes (1965–66, 1967–68 and 1969–70).

In general, the effect of drainage was seen first in the fertile site group and in small sample trees. With increasing time period since drainage the change in increment rate levelled off, and growth continued on higher level. In the poor site group the growth rate increased continuously during the entire study period.

All fertilization treatments tended to increase relative sample tree growth during the growth period 1970–74. While in the fertile site group only NPK gave a significant effect, in the nutrient poor site group N and P separately, but particularly in combination, significantly increased growth. There was also a clear difference between the fertile and nutrient poor site group in their response to fertilization. In the latter group, which were low in peat nitrogen and phosphorus, the increase in relative growth of the sample trees was significantly higher after fertilization than in the fertile site group. This trend was consistent for most treatments but significant only in the case of the NP treatment. There was also a clear relationship between the response to fertilization and drainage age. The smallest response to fertilization was in the oldest drainage age class, and the relative importance of nitrogen increased with decreasing time lag between drainage and fertilization i.e. N was more important soon after drainage than later. Thus the positive effect of nitrogen was short-lasting and during 1975–81 there was even an indication of a growth retarding effect of nitrogen fertilization. The only indication of a long-term positive response to fertilization treatment was with the slow releasing phosphorus fertilizer.

Reasons for the unimportance of the K treatment with respect to stand increment are probably related to the shallow peat layer on several experimental fields, and the short time since drainage. In the fertile site group, a positive tendency of K was seen, and when comparing needle K contents on fertilized and non-fertilized sample plots it was obvious that K fertilization had had a long-term influence.

On an average the effect of drainage and fertilization doubled the volume increment during each of the growth periods 1970–74 and 1975–81. However, the absolute influence of the amelioration measures was modest compared to growth on productive forest land (1.0 $m^3 \cdot ha^{-1} \cdot a^{-1}$ during a rotation period), The low absolute effect depends upon the low stand volume of the experimental fields (5–70 $m^3 \cdot ha^{-1}$). The best overall fertilizer response was gained with NPK and NP treatments, which during the eleven year research period gave on an average an additional 3–4 $m^3 \cdot ha^{-1}$. Although individual sample trees on sites of low fertility strongly increased growth after fertilization, on the poorest sites where stand volume also was the lowest the amelioration measures had little effect upon volume increment.

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SELOSTE

KASVUPAIKKOJEN LUOKITUS LANNOITUKSEN ARVIOINNISSA OJITETUILLA RÄMEILLÄ

NPK-lannoituskäsittelyjen vaikutusta puuston kasvuun tutkittiin eräillä Pohjois-Suomen ojitetuilla soilla. Lyhytkortisilla sararämeillä ja niitä paremmilla soilla typpitaloutta on pidetty tyydyttävänä ojituksen jälkeistä puuston kasvua ajatellen. Lannoituskokeen alustava inventointi vuonna 1974 osoitti kuitenkin typen lisäävän kasvua erityisesti yhdessä fosforin kanssa myös paremmilla sararämeillä. Kalium ei ollut vaikuttanut puuston kasvuun.

Koetta uudelleen inventoitaessa vuonna 1981 todettiin, että ennen ojitusta määritetty suokuvion suotyyppi ei kuvastanut kuvion sisälle sijoitetun koekentän viljavuutta riittävän tarkasti. Lisäksi maaperän viljavuus vaihtelee koekenttien sisällä. Täten typpilannoituksella saatu positiivinen vaikutus sararämeillä ja paremmilla suotyypeillä saattoikin johtua näiden koealojen luontaisen viljavuuden yliarvioimisesta. Asian selvittämiseksi päätettiin koeala-aineisto luokitella uudelleen mitattujen maaperätunnusten avulla. Tehtävästä kehittyi tämän tutkimuksen vaativin osatavoite.

Tutkimuksen aineisto perustuu NPK-lannoituskokeeseen, joka perustettiin kesäkuussa 1970 enintään 6 vuotta aikaisemmin ojitetuille rämeille (VLR, RLR, VSR, PsR, KR, LkR, IR, RaR). Aineistossa oli myös mukana kolme korpisuota (KgK, PK ja PsK). Jokaisella koekentällä on vähintään kahdeksan koeruutua: N, P, K, NP, NK, PK, NPK ja lannoittamaton kontrolliruutu. Typpeä annettiin 100 kg · ha^{-1}, fosforia 44 kg · ha^{-1} ja kaliumia 83 kg · ha^{-1}, ja lannoitteena käytettiin oulunsalpietaria, kalisuolaa ja hienofosfaattia. Alunperin perustettiin 27 koekenttää, mutta erilaisista maankäyttötoimenpiteistä johtuen ainoastaan 23 ja 19 koekenttää oli jäljellä vuosien 1974 ja 1981 maastoinventoinneissa.

Mitatun aineiston perusteella laskettiin koepuiden tilavuustunnukset vuosille 1964, 1969, 1974 ja 1981. Keskimääräisiä vuotuisia kasvutunnuksia laskettiin erotusmenetelmällä kasvujaksoille 1965–69, 1970–74 ja 1975–81. Ojituksen vaikutusta lannoittamattomien kontrolliruutujen puuston kasvuun tarkasteltiin tasoitetuilla malleilla, joissa koepuun vuoden 1964 pohjapinta-alalla ennustettiin sen pohjapinta-alan kasvuprosenttia kunakin havaintovuonna. Lannoituskäsittelyn vaikutus koepuiden kasvuun saatiin laskemalla koepuun mitatun kasvuprosentin ja vastaavan arvioidun lannoittamattoman pohjapinta-alan kasvuprosentin erotus. Laskemalla koepuukohtaisista arvioista keskiarvot saatiin koe-alakohtaisia arvioita. Puuston tilavuustunnukset laskettiin koekenttäkohtaisten runkolukusarjojen avulla ja lannoituksen aiheuttamat muutokset johdettiin pohjapinta-alan kasvun kehityksestä.

Molempien inventointien (1974 ja 1981) yhteydessä kerättiin maanäytteitä. Vuonna 1974 näytteet kerättiin kaikilta lannoittamattomilta kontrolliruuduilta (yhteensä 25 ruutua), ja 1981 kaikilta mäntyvaltaisilta koeruuduilta, joilla turpeen paksuus oli suurempi kuin 30 cm (yhteensä 93 ruutua). Vuoden 1981 näytteenkeruussa oli siten mukana sekä lannoitettuja että lannoittamattomia koe-ruutuja. Loka–marraskuussa 1981 kerättiin myös neulasnäytteitä samoilta koeruuduilta, joilta kesällä oli kerätty maanäytteet. Maanäytteistä tutkittiin turpeen tiheys, tuhkapitoisuus, pH, kationinvaihtokapasiteetti ja emäskyllästysaste sekä makro- ja mikroravinteiden kokonaismäärät (N, P, K, Ca, Mg, Fe, ja Mn). Neulasnäytteistä määritettiin tuhkapitoisuus ja samat ravinteet kuin maanäytteistä. Maaperätunnukset ilmaistiin volumetrisina määrinä ja muunnettiin suhteellisiksi siten, että jokaisen muuttujan keskiarvoksi tuli likimäärin 50 ja vaihteluväliksi 0–100.

Kahdeltatoista kontrolliruudulta maanäytteet kerättiin sekä 1974 että 1981. Vuoden 1974 ja vuoden 1981 maanäyteaineistojen vertailussa voitiin todeta, että kontrolliruutujen maaperätunnuksissa ei ollut tapahtunut merkitseviä muutoksia näiden kahden näytekeruuajankohdan välisenä aikana. Analyysitulosten yhteensopivuus oli erityisen hyvä typen ja fosforin osalta. Kokonaisuuksina vuosien 1974 ja 1981 maaperänäytteet (25 ja 93 koeruutua) edustavat kuitenkin kahta hieman erilaista aineistoa. Aineistojen suotyyppijakaumat ovat erilaiset (1981 suotyyppijakauma on osajoukko 1974 suotyyppijakaumasta) ja kerättyjen turvekerrosten paksuudet vaihtelevat (1974 kairattiin 20 cm:n näyte ja 1981 30 cm:n näyte). Lisäksi vuoden 1981 maaperäaineistoon kuului sekä lannoitettuja että lannoittamattomia koeruutuja, kun vuoden 1974 aineistoon kuuluivat ainoastaan lannoittamattomat kontrolliruudut. Vuoden 1981 aineisto oli kuitenkin homogeenisempi kuin vuoden 1974 aineisto ja käsitti kaikki edellä mainitut maaperätunnukset. Tämän takia edellä mainittua aineistoa käytettiin perusmateriaalina ja viimeksimainittua riippumattomana kontrolliaineistona.

Aineiston sisäisten viljavuusgradienttien selvittämiseksi koeruudut ordinoitiin 1981 aineistoa käyttäen decorana-analyysillä. Ilmeni että aineistossa oli kaksi maaperällistä gradienttia jotka yhdessä kuvastivat trofiaa. Decorana-analyysin ensimmäinen akseli, jonka pisteet olivat korreloituneet turpeen typen, fosforin ja raudan kokonaismääriin, kuvasti kasvavaa maatuneisuutta ja alla olevan kivennäismateriaalin kasvavaa vaikutusta. Decorana-analyysin toinen ja kolmas akseli olivat korreloituneet turpeen pH arvoon ja emäskationien määrään ja kuvastivat siten happo-emäs gradienttia.

Koe-alojen ryhmittämiseksi objektiivisellä tavalla maaperäominaisuuksien mukaisesti laskettiin 1981 aineistoa edelleen käyttäen twinspan-analyysiä. Pääasiallisesti edellä kuvattujen gradienttien mukaisesti erottui analyysissä viisi koealaryhmää. Muodostettujen ryhmien maaperälliset piirteet kuvastuivat johdonmukaisesti koeruutujen puuston ominaisuuksissa. Myös neulasten ravinnetunnuksissa voitiin todeta, että typen, fosforin, kaliumin, kalsiumin ja magnesiumin pituuskasvaimen pituudella painotetut ravinnepitoisuudet olivat korkeimmat viljaviksi luokitelluissa koe-alaryhmissä. Neulasten mangaaniarvo oli selvästi korkein koealaryhmässä, joka erottui turpeen korkean mangaanipitoisuuden avulla.

Koska vuoden 1974 maanäytteistä oli analysoitu vain osa vuoden 1981 aineistosta analysoiduista tunnuksista, ne eivät olleet mukana twinspan-analyysissä. Vertailemalla twinspan maaperäryhmien taulukko-ominaisuuksiin oli mahdollista luokitella niitä koekenttiä, joilla maanäytteitä oli kerätty ainoastaan kontrolliruuduilta vuonna 1974. Jotta tällainen luokitus voitaisiin suoritta matemaattisesti, laskettiin askeltava erotteluanalyysi käyttäen twinspan-maaperäryhmää luokkamuuttujana. Vertailemalla regressioyhtälöillä saatua luokitustulosta alkuperäiseen twinspan-luokitukseen voitiin todeta, että yhtälöt ilmaisivat riittävällä tarkkuudella twinspan-maaperäryhmien ominaisuuksia. Koko koe-ala aineistosta (93 koeruutua) 80 koe-alaa voitiin yhtälöillä luokitella oikein.

Verrattaessa kokeen alustavassa inventoinnissa käytettyä suotyyppiluokitusta maaperäominaisuuksiin perustuvien twinspan- ja erotteluanalyysien antamiin luokituksiin selvisi, että koekenttien sisäinen heterogeenisyys oli vaikuttanut vuoden 1974 alustavien koetulosten tulkintaan. Muutamilla koekentillä yksittäisten koeruutujen maaperän viljavuus oli ilmiselvästi alhaisempi kuin koekentälle määritetyn suotyypin keskimääräinen luontainen viljavuus. Päinvastaistakin vaihtelua esiintyi. Myös alunperin karuiksi luokitelluilta koekentiltä löytyi suhteellisen viljaviakin koe-ruutuja. Maaperän ominaisuuksiin perustuvalla luokitusmenetelmällä pystyttiin kuvaamaan koeruutujen ja koekenttien viljavuutta paremmin kuin pintakasvillisuuteen perustuvalla suotyypillä.

Lannoituskokeen kasvutulosten lopullisessa tarkastelussa koe-ala aineisto ryhmiteltiin kahteen viljavuusluokkaan. Kaksi viljavinta twinspan-ryhmää käsiteltiin yhtenä luokkana ja kolmas, viljavuudeltaan keskimääräinen ryhmä yhdistettiin kahden karuimman ryhmän kanssa toiseksi luokaksi. Molemmat viljavuusluokat jaettiin edelleen ojituksen ajankohdan mukaan kolmeen ikäluokkaan (1965–66, 1967–68, 1969–70). Ojituksen vaikutus kontrolliruutujen koepuiden kasvun kiihdyttäjänä nähtiin ensimmäiseksi viljavilla kasvupaikoilla ja pienissä koepuissa. Mitä pitempi aika oli kulunut ojituksesta, sitä täydellisemmin kasvun taso oli muuttunut.

Lannoituksen vaikutusta puiden kasvuun tarkasteltiin erikseen kasvupaikan viljavuuden ja ojitusiän suhteessa. Yleisesti lannoitus näytti vaikuttavan kasvuun lannoitusta välittömästi seuranneen tarkastelujakson aikana. Viljavilla kasvupaikoilla saatiin merkitsevästi suurempi kasvu ainoastaan NPK-käsittelyllä, kun taas karuilla kasvupaikoilla N ja P erikseen ja erityisesti yhdistettynä lisäsivät kasvua merkitsevästi. Karuilla kasvupaikoilla kasvunlisäys oli lähes kaikilla käsittelyillä selvästi suurempi kuin viljavilla kasvupaikoilla. Viljavuusluokkien välinen ero oli kuitenkin merkitsevä ainoastaan NP-käsittelyssä. Lannoituksen tehon ja ojituksesta kuluneen ajan välillä oli myös selvä riippuvuus. Vanhimmassa ojitusikäryhmässä lannoitusvaikutus oli pienin ja typpilannoituksen suhteellinen merkitys kasvoi kun ojituksesta kulunut aikaväli pieneni.

Typpilannoituksen kasvua lisäävä vaikutus oli kuitenkin lyhytaikainen. Tarkastelujaksona 1975–81 oli havaittavissa enää vain hidasliukoisen fosforilannoitteen positiivista vaikutusta. Typpilannoitus näytti jopa johtavan lievään kasvun taantumiseen tällä tarkastelujaksolla.

Kaliumlannoituksen vähäinen vaikutus puuston kasvuun johtui siitä, että koekenttien turvekerros oli ohut. Lisäksi alhainen ojitusikä lannoitushetkellä vaikutti koekenttien kaliumtalouteen. Viljavilla kasvupaikoilla, missä kasvu oli suurin ja koepuiden kasvureaktiot nopeimmat, voitiin kuitenkin todeta merkkejä K-käsittelyn positiivisesta vaikutuksesta, ja kun verrattiin kaliumilla lannoitettujen koepuiden neulasten K-arvoja vuonna 1981 lannoittamattomien koepuiden arvoihin ilmeni, että K-käsittely vielä 11 vuotta levityksen jälkeen vaikutti neulasten kaliumpitoisuuksiin.

Siitä huolimatta, että lannoitus vaikutti selvästi yksittäisten koepuiden kasvuun, kokeessa todettiin, että metsänparannustoimenpiteiden vaikutus tilavuuskasvuun oli vaatimaton näillä Pohjois-Suomen vähäpuustoisilla soilla. Useimmissa tapauksissa keskimääräinen vuotuinen kasvu jaksolla 1971–81 ei edes yltänyt kasvullisen metsämaan minimikasvun tasolle. Paras välitön kasvutulos savutettiin NPK, NP ja NK lannoituskäsittelyillä ja myöhemmin tarkastelujakson aikana P käsittelyn merkitys kasvoi. Yhdentoista vuoden pituisen tutkimusjakson aikana NPK- ja NP-käsittelyt antoivat 3–4 $m^3 \cdot ha^{-1}$ suuruisen kasvunlisäyksen kun samana jaksona P ja PK käsittelyt nostivat kasvua n. 2 $m^3 \cdot ha^{-1}$. Aineiston kaikkein karuimmilla ja samalla vähäpuustoisimmilla kohteilla lannoituksella (ja ojituksella) oli hyvin vähäinen vaikutus kasvuun.

Appendix 1. Fertilizer treatment and tree stand data for sample plots inventoried in 1981.

Experimental field	Sample plot	Soil sampling		Fertilizer treatment	Basal area of sample trees in 1974, $m^2 \cdot ha^{-1}$	Sample plot tree stand species composition in 1974, %			Stand volume increment, $m^3 \cdot ha^{-1}$			Stand volume 1981, $m^3 \cdot ha^{-1}$
		1974	1981			Scots pine	Norway spruce	hardwoods	1965–69	1970–74	1975–81	
1	2			K	12.0	–	90	10	3.0	3.5	7.0	30.5
1	3			NPK	14.0	–	70	30	4.1	6.7	15.7	48.7
1	9			N	16.0	–	80	20	5.0	7.1	13.2	53.3
1	10			NP	10.5	–	90	10	3.9	5.7	11.3	35.2
1	11			NPK	15.0	–	80	20	3.8	6.1	14.4	44.7
1	13			PK	11.0	–	80	20	2.3	3.2	6.5	25.3
1	14			NK	15.0	–	80	20	4.0	6.1	8.3	33.2
1	15			NPK	9.0	–	90	10	2.1	3.4	7.9	24.6
1	16			P	8.0	–	80	20	2.7	3.7	9.3	32.1
1	17	+		contr.	16.5	–	70	30	5.1	5.1	15.1	46.6
1	18			PK	12.0	–	70	30	2.9	3.9	8.0	31.2
1	21			PK	15.5	–	90	10	4.1	5.6	11.4	44.8
2	1			NP	3.0	80	10	10	0.9	1.8	8.1	13.8
2	2	+		contr.	4.0	90	–	10	1.2	1.6	7.7	13.3
2	3			NPK	5.5	80	10	10	1.2	3.4	10.0	18.2
2	4			K	2.0	100	–	–	0.7	1.6	6.6	10.5
2	5			N	1.0	80	10	10	0.5	1.4	6.8	9.8
2	6			NK	3.0	90	10	–	1.0	1.8	7.1	12.9
2	7			PK	3.0	80	20	–	0.6	1.4	8.6	11.8
2	8			P	1.0	90	–	10	1.8	3.8	16.4	26.6
3	1			NPK	12.0	40	40	20	7.1	9.4	12.5	55.2
3	2			NP	10.0	30	60	20	2.9	5.5	8.0	36.3
3	3			N	10.0	40	40	20	4.7	7.3	10.6	43.9
3	4			NK	6.5	40	50	10	1.8	3.5	5.9	28.0
3	5			PK	9.0	10	70	20	3.1	4.2	6.9	32.2
3	6	+		contr.	8.5	20	60	20	2.0	3.5	6.3	27.3
3	7			K	12.0	10	60	30	2.5	3.4	10.2	34.9
3	8			P	18.0	–	60	40	7.0	7.4	19.7	59.6
5	1		+	NK	9.0	80	10	10	2.5	5.8	18.2	39.7
5	2		+	P	5.5	90	–	10	2.2	4.5	18.7	35.6
5	3		+	K	9.0	80	–	20	2.5	7.2	24.3	44.1
5	4		+	PK	10.5	90	–	10	2.7	9.4	26.6	51.3
5	5		+	NPK	7.0	80	10	10	1.7	7.4	21.1	36.9
5	6		+	N	5.0	90	10	–	1.7	4.0	12.7	25.0
5	7	+	+	contr.	8.0	70	20	10	2.8	4.9	10.9	34.0
5	8		+	NP	8.0	100	–	–	1.6	8.0	26.9	39.3
7	1		+	NK	4.5	40	–	60	2.8	4.6	8.9	27.5
7	2		+	N	4.5	40	–	60	1.2	1.7	2.4	9.1
7	3		+	NPK	5.0	40	–	60	1.2	4.4	13.6	24.5
7	4		+	P	3.5	40	–	60	1.4	2.9	7.9	16.7
7	5	+	+	contr.	4.0	50	–	50	1.2	1.7	4.0	12.1
7	6		+	K	5.0	50	–	50	2.0	3.2	8.9	20.4
7	7		+	PK	4.5	50	–	50	0.8	1.9	8.4	13.9
7	8		+	NP	7.0	70	10	20	1.5	4.1	12.4	23.0

Experimental field	Sample plot	Soil sampling		Fertilizer treatment	Basal area of sample trees in 1974, $m^2 \cdot ha^{-1}$	Sample plot tree stand species composition in 1974, %			Stand volume increment, $m^3 \cdot ha^{-1}$			Stand volume 1981, $m^3 \cdot ha^{-1}$
		1974	1981			Scots pine	Norway spruce	hardwoods	1965–69	1970–74	1975–81	
10	1		+	NPK	1.5	60	30	10	0.7	1.7	4.2	8.2
10	2		+	N	3.0	50	40	10	1.5	2.0	3.3	10.4
10	3		+	NP	2.0	50	50	–	0.5	1.1	2.0	5.0
10	4	+	+	contr.	2.0	60	40	–	0.6	0.9	2.6	5.6
10	5		+	NK	1.0	50	50	–	0.6	1.3	2.8	6.3
10	6		+	K	4.0	50	50	–	0.6	1.0	2.1	5.1
10	7		+	PK	0.5	50	50	–	0.3	0.6	1.7	3.3
10	8		+	P	~	60	40	–	0.4	0.7	2.3	4.0
11	1			NK	13.5	90	10	–	4.6	9.7	16.0	65.5
11	2			NP	15.0	70	20	10	5.4	8.0	18.3	67.6
11	3			P	15.0	50	30	20	6.1	9.9	20.1	70.3
11	4			K	17.0	90	5	5	6.7	7.0	13.2	62.6
11	5			NPK	12.0	80	–	20	4.7	13.7	15.5	50.5
11	6	+		contr.	13.0	100	–	–	5.5	9.4	12.4	64.0
11	7			PK	6.0	100	–	–	3.4	8.6	17.5	41.6
11	8			N	11.0	100	–	–	2.3	4.3	8.8	43.8
12	1			PK	2.0	100	–	–	0.8	3.2	10.5	16.6
12	2			P	6.0	100	–	–	1.7	7.4	16.1	29.8
12	3			N	4.0	100	–	–	1.3	2.1	2.7	11.9
12	4	+		contr.	4.0	100	–	–	1.4	3.1	7.1	16.0
12	5			NP	8.0	100	–	–	2.4	5.7	10.1	27.5
12	6			K	6.0	100	–	–	2.3	4.2	7.5	27.1
12	7			NK	5.0	100	–	–	1.4	3.1	6.2	16.2
12	8			NPK	6.0	100	–	–	2.4	5.1	10.6	27.1
13	1		+	P	4.5	90	–	10	1.5	4.5	13.9	23.7
13	2	+	+	contr.	5.0	70	10	20	1.9	4.5	13.0	24.5
13	3		+	K	4.0	90	–	10	1.1	3.7	19.6	26.2
13	4		+	NPK	12.0	60	20	20	3.4	11.3	22.8	54.0
13	5		+	PK	10.0	60	10	30	3.7	5.5	13.1	52.7
13	6		+	NK	9.0	60	–	40	3.2	9.9	21.3	50.8
13	7		+	NP	9.5	80	–	20	3.7	7.5	22.8	44.7
13	8		+	N	7.0	80	–	20	2.9	4.6	16.9	32.7
14	1	+	+	contr.	2.0	80	20	–	1.2	1.4	4.6	11.7
14	2		+	PK	2.5	90	10	–	1.3	2.4	7.4	15.8
14	3			NPK	4.5	30	50	20	1.0	4.6	9.1	18.7
14	4			PK	8.0	10	20	70	2.5	4.4	13.7	29.3
14	5	+		contr.	6.5	20	40	40	3.7	4.2	14.0	35.6
14	6		+	NPK	4.5	80	20	–	1.3	5.8	11.6	23.9
14	7		+	NK	9.0	80	20	–	2.4	6.8	14.0	28.7
14	8		+	K	3.0	90	10	–	1.4	2.1	8.6	15.6
14	9		+	NP	3.0	80	20	–	0.9	6.7	7.9	19.0
14	10		+	P	2.0	70	30	–	0.9	1.9	5.8	13.2
14	11		+	N	3.0	70	30	–	1.4	5.5	10.5	22.7
14	12			P	5.0	10	40	50	1.8	3.6	11.2	25.3
14	13	+	+	contr.	4.5	70	20	10	2.0	2.2	7.4	18.9
14	14		+	PK	4.0	60	30	10	1.9	3.3	10.3	22.0
14	15		+	P	2.5	90	10	–	1.2	2.5	7.7	17.4
14	16		+	NPK	3.5	90	10	–	1.1	5.2	10.4	21.4

Experimental field	Sample plot	Soil sampling		Fertilizer treatment	Basal area of sample trees in 1974, $m^2 \cdot ha^{-1}$	Sample plot tree stand species composition in 1974, %			Stand volume increment, $m^3 \cdot ha^{-1}$			Stand volume 1981, $m^3 \cdot ha^{-1}$
		1974	1981			Scots pine	Norway spruce	hardwoods	1965–69	1970–74	1975–81	
15	17			PK	5.0	30	50	20	1.7	4.7	11.7	25.1
15	18	+	+	contr.	3.5	60	30	10	1.7	2.8	9.8	20.6
15	19		+	N	3.5	60	30	10	1.6	5.0	8.9	21.1
15	20			NPK	6.5	20	40	40	2.4	8.1	11.2	36.0
15	21		+	NP	5.0	70	20	10	1.2	5.3	9.8	22.4
15	22		+	K	3.0	70	20	10	1.6	3.2	8.3	16.1
15	23		+	NK	4.0	50	40	10	1.1	4.6	9.3	17.3
15	24			P	3.0	30	50	20	1.9	3.0	5.4	16.7
16	1		+	PK	8.0	100	–	–	1.2	1.5	4.5	28.9
16	2		+	P	5.0	100	–	–	1.2	1.5	5.7	18.5
16	3		+	NK	8.0	100	–	–	2.6	5.8	8.3	37.7
16	4	+	+	contr.	3.5	100	–	–	0.7	0.8	3.6	10.4
16	5		+	NP	10.5	100	–	–	2.8	4.6	8.8	63.8
16	6		+	NPK	7.0	100	–	–	1.9	4.4	13.8	33.6
16	7		+	K	11.0	100	–	–	2.1	2.4	8.8	49.2
16	8		+	N	6.5	100	–	–	1.2	1.7	5.7	24.4
18	1		+	P	1.5	100	–	–	0.3	0.9	3.1	5.9
18	2	+	+	contr.	3.0	100	–	–	0.3	0.7	2.5	5.4
18	3		+	NK	4.0	100	–	–	0.4	1.2	3.7	8.5
18	4		+	K	3.0	100	–	–	0.3	0.9	3.8	6.1
18	5		+	PK	4.0	100	–	–	0.3	1.2	5.2	8.5
18	6		+	NPK	4.5	100	–	–	0.4	1.7	5.9	11.7
18	7		+	NP	4.0	100	–	–	0.4	1.8	4.9	9.5
18	8		+	N	5.0	100	–	–	0.5	1.3	4.7	11.7
20	1		+	N	6.0	100	–	–	2.1	4.9	10.6	30.4
20	2		+	PK	7.0	100	–	–	1.3	3.6	13.5	26.4
20	3	+	+	contr.	8.5	100	–	–	2.0	2.2	7.4	28.5
20	4		+	NK	8.0	100	–	–	3.0	4.6	9.9	44.9
20	5		+	NP	9.0	100	–	–	3.0	9.7	15.3	40.6
20	6		+	K	9.5	100	–	–	4.5	5.3	12.9	41.2
20	7		+	P	11.5	100	–	–	3.1	9.4	22.2	52.1
20	8		+	NPK	7.0	100	–	–	3.6	6.1	14.6	40.1
22	1		+	K	5.0	100	–	–	1.2	1.4	3.2	19.0
22	2		+	P	1.5	100	–	–	0.4	1.1	7.5	10.1
22	3		+	NP	3.0	100	–	–	0.8	3.5	7.1	14.0
22	4	+	+	contr.	3.5	100	–	–	0.8	1.1	3.7	11.3
22	5		+	N	5.5	100	–	–	0.9	3.2	7.9	16.4
22	6		+	NPK	4.5	100	–	–	0.6	4.4	10.1	17.3
22	7		+	NK	7.0	100	–	–	1.4	4.3	10.2	23.6
22	8		+	PK	3.5	100	–	–	0.7	2.0	9.6	16.0
23	1		+	N	1.5	70	10	20	0.6	1.4	7.4	10.9
23	2		+	NP	4.0	90	10	–	0.8	2.1	9.4	20.8
23	3		+	PK	1.0	90	–	10	0.2	0.6	8.7	9.9

Experimental field	Sample plot	Soil sampling 1974	Soil sampling 1981	Fertilizer treatment	Basal area of sample trees in 1974, $m^2 \cdot ha^{-1}$	Sample plot tree stand species composition in 1974, %: Scots pine	Norway spruce	hardwoods	Stand volume increment, $m^3 \cdot ha^{-1}$: 1965–69	1970–74	1975–81	Stand volume 1981, $m^3 \cdot ha^{-1}$
23	4	+	+	contr.	4.0	90	–	10	0.7	1.9	10.4	15.2
23	5		+	P	2.0	100	–	–	~	~	13.9	14.0
23	6		+	NPK	5.5	100	–	–	0.6	4.2	17.1	23.8
23	7		+	K	6.0	100	–	–	1.7	3.1	10.8	22.2
23	8		+	NK	7.0	90	10	–	1.7	4.6	24.8	36.2
24	1			PK	9.0	80	10	10	3.9	4.7	9.9	34.1
24	2			P	12.0	80	10	10	7.4	8.6	17.9	61.4
24	3			NP	14.0	90	10	–	5.6	9.0	16.4	62.4
24	4			K	6.0	100	–	–	1.6	2.9	13.4	25.2
24	5	+		contr.	15.0	80	20	–	6.1	6.0	17.8	58.4
24	6			NK	8.5	100	–	–	1.8	3.1	9.8	31.6
24	7			NPK	14.5	90	10	–	5.3	8.8	25.2	60.1
24	8			N	6.0	90	–	10	1.4	2.9	9.8	22.5
25	1			NP	6.5	70	20	10	3.5	7.8	16.5	36.9
25	2			NPK	12.5	90	10	–	4.6	12.5	20.1	66.9
25	3			PK	10.5	60	30	10	3.6	4.1	8.2	30.5
25	4			N	12.0	80	10	10	4.4	8.9	22.7	58.4
25	5	+		contr.	8.5	60	30	10	6.1	6.1	13.3	39.4
25	6			P	12.0	80	10	10	4.8	5.8	16.3	54.3
25	7			K	8.0	70	20	10	5.0	6.6	14.5	40.1
25	8			NK	10.0	80	20	–	4.7	8.5	16.2	43.4
27	1		+	K	2.5	90	10	–	0.5	1.2	5.2	8.3
27	2		+	PK	3.5	50	40	10	0.9	1.9	4.6	10.7
27	3			NK	3.5	20	50	30	1.0	3.2	6.1	14.6
27	4		+	P	3.0	80	20	–	1.1	2.2	5.9	13.2
27	5	+		contr.	3.0	20	50	30	1.1	1.7	4.2	10.8
27	6		+	NP	2.5	80	20	–	0.3	3.5	9.9	14.3
27	7			NPK	4.0	70	30	–	0.8	5.2	10.0	18.1
27	8			N	6.0	70	10	20	1.5	4.3	8.9	21.3

Appendix 2. Fertilizer treatment, peatland site type, twinspan fertility level (1 poor and 5 rich) of some important soil variables in the 1981 soil data, twinspan edaphic group of sample plots on the basis of the 1981 soil data, twinspan edaphic group indices for fertilized sample plots on the bases of 1981 soil data and the simplified discriminating equations in Table 9, and twinspan edaphic group indices for non-fertilized control plots on the basis of 1981 and 1974 soil sample data and the simplified equations in Table 9.

Experimental field	Sample plot	Fertilizer treatment	Peatland site type	TS fertility level of some important soil variables in the 1981 soil data: pH	N	P	K	Ca	TS edaphic group, 1981 soil data	Discrimination of sample plots into TS groups, 1981 soil data	Classification of nonfertilized control plots into TS groups, 1981 soil data	1974 soil data
5	3	K	VSR	5	5	3	3	5	00	00	· ·	· ·
5	7	contr.	VSR	5	5	5	2	5	00	· ·	00	00
5	8	NP	VSR	5	5	5	3	5	00	00	· ·	· ·
13	14	NPK	VSR	5	5	5	5	5	00	00	· ·	· ·
5	1	NK	VSR	4	4	4	5	4	00	01	· ·	· ·
13	1	P	VSR	4	4	5	3	3	00	00	· ·	· ·
13	3	K	VSR	5	4	4	4	4	00	00	· ·	· ·
13	7	NP	VSR	3	5	5	4	3	00	00	· ·	· ·
13	8	N	VSR	4	5	5	3	3	00	00	· ·	· ·
23	5	P	LkR	5	4	5	3	4	00	00	· ·	· ·
13	2	contr.	VSR	4	5	5	5	5	00	· ·	00	00
13	5	PK	VSR	5	5	5	5	5	00	00	· ·	· ·
13	6	NK	VSR	5	5	5	5	5	00	00	· ·	· ·
5	4	PK	VSR	4	5	5	3	5	00	00	· ·	· ·
23	1	N	LkR	5	5	5	4	5	00	00	· ·	· ·
23	3	PK	LkR	5	5	5	3	5	00	00	· ·	· ·
23	8	NK	LkR	4	5	5	5	4	00	00	· ·	· ·
1	17	contr.	PsK	·	·	·	·	·	· ·	· ·	· ·	00
2	2	contr.	PsR	·	·	·	·	·	· ·	· ·	· ·	00
11	6	contr.	PsR	·	·	·	·	·	· ·	· ·	· ·	00
25	5	contr.	PK	·	·	·	·	·	· ·	· ·	· ·	00
26	8	contr.	VSN	·	·	·	·	·	· ·	· ·	· ·	00
7	7	PK	IR	4	5	3	5	5	01	01	. .	. .
5	5	NPK	VSR	4	3	3	2	4	01	01	. .	. .
10	7	PK	PsR	4	2	2	5	4	01	**100**	. .	. .
23	6	NPK	LkR	4	4	4	3	4	01	01	. .	. .
27	1	K	PsR	3	3	3	3	4	01	01	. .	. .
7	2	N	IR	4	4	3	3	4	01	01	. .	. .
7	3	NPK	IR	4	4	3	3	4	01	01	. .	. .
7	6	K	IR	4	4	4	3	4	01	01	. .	. .
7	8	NP	IR	4	4	4	4	4	01	01	. .	. .
7	1	NK	IR	4	3	3	2	4	01	01	. .	. .
7	4	P	IR	4	3	3	3	3	01	01	. .	. .
10	3	NP	PsR	4	2	3	2	4	01	01	. .	. .
27	4	P	PsR	2	3	3	4	4	01	01	. .	. .
10	5	NK	PsR	4	2	4	3	3	01	01	. .	. .
10	8	P	PsR	5	1	2	3	5	01	01	. .	. .
23	7	K	LkR	5	4	4	4	5	01	**00**	. .	. .

Experimental field	Sample plot	Fertilizer treatment	Peatland site type	TS fertility level of some important soil variables in the 1981 soil data					TS edaphic group, 1981 soil data	Discrimination of sample plots into TS groups,	Classification of nonfertilized control plots into TS groups,	
				pH	N	P	K	Ca		1981 soil data	1981 soil data	1974 soil data
27	2	PK	PsR	3	4	4	4	5	01	01	. .	. .
24	5	contr.	VSR	.	.	.	.	.	. .	. .	. .	01
27	5	contr.	PsR	.	.	.	.	.	. .	. .	. .	01
15	19	N	KR	2	3	2	3	4	100	100	. .	. .
14	9	NP	PsR	3	2	2	2	4	100	100	. .	. .
15	18	contr.	KR	3	2	2	4	4	100	. .	100	100
15	21	NP	KR	3	2	2	3	4	100	100	. .	. .
15	22	K	KR	3	2	1	3	4	100	100	. .	. .
14	1	contr.	PsR	3	1	1	2	3	100	. .	**101**	100
14	2	PK	PsR	2	2	2	2	5	100	100	. .	. .
14	10	P	PsR	2	2	2	1	3	100	**101**	. .	. .
14	16	NPK	PsR	2	2	2	2	2	100	100	. .	. .
14	7	NK	PsR	2	3	2	5	3	100	100	. .	. .
14	8	K	PsR	2	3	1	3	3	100	100	. .	. .
14	14	PK	PsR	3	3	2	3	3	100	100	. .	. .
14	5	contr.	PsR	.	.	.	.		. .	. .	. .	100
5	2	P	VSR	3	3	2	2	2	101	**100**	. .	. .
14	15	P	PsR	2	2	1	2	3	101	**100**	. .	. .
16	1	PK	RaR	3	2	2	4	2	101	**100**	. .	. .
22	2	P	RaR	3	2	2	2	2	101	**100**	. .	. .
5	6	N	VSR	3	2	3	3	2	101	101	. .	. .
14	6	NPK	PsR	2	1	1	2	2	101	101	. .	. .
14	13	contr.	PsR	1	2	1	3	1	101	. .	**100**	**100**
15	23	NK	KR	2	2	2	4	3	101	101	. .	. .
16	3	NK	RaR	2	2	2	3	2	101	101	. .	. .
18	7	NP	PsR	1	1	1	1	1	101	101	. .	. .
20	1	N	VLR	2	2	2	1	2	101	101	. .	. .
20	2	PK	VLR	2	2	2	3	2	101	101	. .	. .
20	3	contr.	VLR	2	2	2	1	2	101	101	. .	. .
20	4	NK	VLR	2	2	2	4	2	101	101	. .	. .
20	6	K	VLR	2	3	2	3	2	101	101	. .	. .
22	1	K	RaR	2	2	2	3	1	101	101	. .	. .
22	3	NP	RaR	4	2	2	3	3	101	101	. .	. .
22	4	contr.	RaR	2	2	2	2	1	101	. .	101	**100**
22	6	NPK	RaR	2	2	2	3	2	101	101	. .	. .
22	8	PK	RaR	3	2	3	3	2	101	101	. .	. .
18	1	P	PsR	3	1	1	1	1	101	101	. .	. .
18	2	contr.	PsR	3	1	1	1	1	101	. .	101	101
18	3	NK	PsR	2	1	1	2	1	101	101	. .	. .
18	4	K	PsR	1	1	1	2	1	101	101	. .	. .
18	5	PK	PsR	2	1	1	1	1	101	101	. .	. .
18	6	NPK	PsR	2	1	1	2	1	101	101	. .	. .
22	5	N	RaR	3	1	1	2	1	101	101	. .	. .
14	11	N	PsR	2	1	1	2	2	101	101	. .	. .
10	1	NPK	PsR	3	2	3	3	3	101	101	. .	. .
10	6	K	PsR	3	2	2	3	3	101	101	. .	. .
27	6	NP	PsR	3	2	3	3	3	101	101	. .	. .
10	2	N	PsR	3	1	1	2	2	101	101	. .	. .
18	8	N	PsR	3	1	2	2	1	101	101	. .	. .

Experimental field	Sample plot	Fertilizer treatment	Peatland site type	TS fertility level of some important soil variables in the 1981 soil data					TS edaphic group, 1981 soil data	Discrimination of sample plots into TS groups,	Classification of nonfertilized control plots into TS groups,	
				pH	N	P	K	Ca		1981 soil data	1981 soil data	1974 soil data
3	6	contr.	PsR	.	.	.	.	.	. .	. .	. .	101
12	4	contr.	LkR	.	.	.	.	.	. .	. .	. .	101
21	7	contr.	LkR	.	.	.	.	.	. .	. .	. .	101
16	2	P	RaR	2	4	4	4	2	11	11	. .	. .
20	5	NP	VLR	2	4	3	1	3	11	11	. .	. .
20	7	NPK	VLR	2	4	4	2	3	11	11	. .	. .
16	4	contr.	RaR	1	3	4	2	1	11	. .	11	11
16	6	NPK	RaR	1	3	3	2	1	11	**101**	. .	. .
16	8	N	RaR	1	4	3	3	1	11	11	. .	. .
22	7	NK	RaR	2	3	3	4	3	11	11	. .	. .
16	5	NP	RaR	3	4	4	3	2	11	11	. .	. .
16	7	K	RaR	3	4	5	4	1	11	11	. .	. .
23	2	NP	LkR	3	4	5	3	2	11	11	. .	. .
23	4	contr.	LkR	3	4	5	3	2	11	. .	11	**00**
7	5	contr.	IR	3	3	2	3	3	11	. .	**01**	**01**
10	4	contr.	PsR	3	2	3	4	2	11	. .	11	**100**
20	8	P	VLR	2	3	3	4	2	11	**01**	. .	. .
4	7	contr.	KgK	.	.	.	.	.	. .	. .	. .	11
17	4	contr.	RLR	.	.	.	.	.	. .	. .	. .	11

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