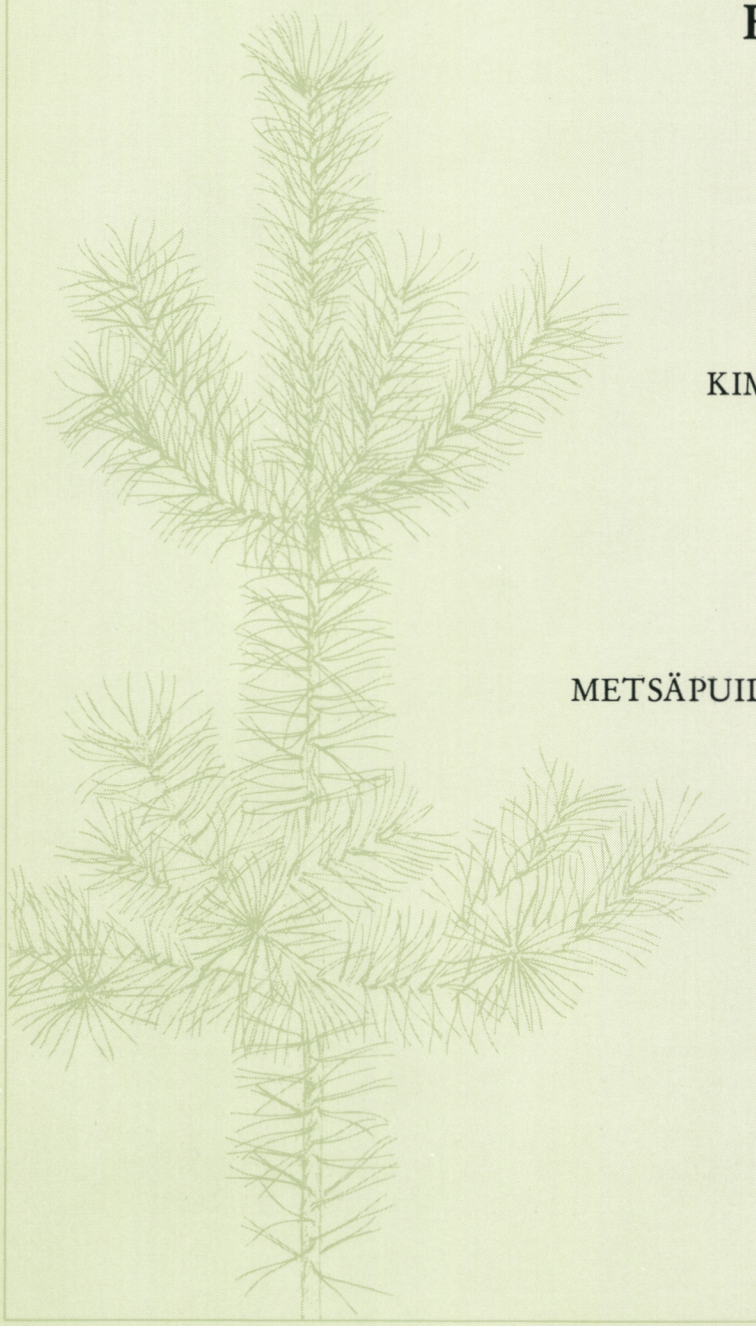
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METSÄNTUTKIMUSLAITOS
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GROWTH DISTURBANCES OF FOREST TREES



KIMMO K. KOLARI (ED.)

SELOSTE

METSÄPUIDEN KASVUHÄIRIÖT

HELSINKI 1983

COMMUNICATIONES INSTITUTI FORESTALIS FENNIAE

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Cover (front & back): Scots pine (*Pinus sylvestris* L.) is the most important tree species in Finland. Pine dominated forest covers about 60 per cent of forest land and its total volume is nearly 700 mil. cu.m. The front cover shows a young Scots pine and the back cover a 30-metre-high, 140-year-old tree.

COMMUNICATIONES INSTITUTI FORESTALIS FENNIAE
116

KIMMO K. KOLARI (Ed.)

GROWTH DISTURBANCES OF FOREST TREES

Proceedings of international workshop and excursion held in Jyväskylä and Kivisuo, Finland, 10.—13. October, 1982

SELOSTE

METSÄPUIDEN KASVUHÄIRIÖT

Jyväskylässä ja Kivisuolla 10.—13. lokakuuta, 1982
pidetyn kansainvälisen symposiumin esitelmäraportit

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The Finnish Forest Research Institute and the IUFRO Working Party SI. 05—01 (Peatland forestry) jointly organized an international workshop on growth disturbances in Jyväskylä, Finland, in October 10.—13. 1982. Altogether 42 scientists from eight countries participated.

During the 1970's, growth disturbances of forest trees came to the focus of forest research particularly in the Nordic countries, but also in Central and eastern Europe, in fact everywhere where previously treeless areas had been afforested. Research in this field is already quite advanced in Australia and New Zealand.

In general, growth disturbances of trees seem to be linked to lack of balance in their nutrition. Symptoms of deficiency of the known main nutrients are not counted as growth disturbances. Growth disturbances lead to the death of the tree tops and to remarkable deterioration in the quality of timber. Trees become knotty, twisted and many-branched. Their use as sawwood is not possible. This problem is being investigated since 1976 in a special research project of the Finnish Forest Research Institute under the leadership of prof. Olavi Huikari. Also in Norway and Sweden growth disturbances are having considerable influence on forestry which has resulted in increased interest in the problem among scientists. In Finland also some physicists are interested in the matter. Increased susceptibility to diseases is usually connected with growth disturbances. In addition, several fungus diseases cause almost similar symptoms as growth disturbances. In the last few years growth disturbances have caught the interest of scientists investigating the viruses in forest trees.

The post-workshop excursion acquainted the participants with the large fertilization experimental fields on Kivisuo at Leivonmäki. Growth disturbances in Scots pine and consequent death of such trees could be seen in vast areas.

IUFROn Working Party SI. 05—01 (Peatland forestry) sekä Metsäntutkimuslaitos järjestivät kansainvälisen kasvuhäiriösymposiumin, johon osallistui 42 tutkijaa 8:sta eri maasta.

Metsäpuiden kasvuhäiriöt ovat tulleet metsäntutkimuksen kiinnostuksen kohteeksi 1970-luvulla erityisesti Pohjoismaissa, mutta myös Keski-Euroopassa, Itä-Euroopassa sekä muualla, missä ennestään puuttomia alueita on metsitetty. Australiassa ja Uudessa Seelannissa alan tutkimus on edennyt jo hyvin pitkälle.

Yleisesti ottaen puiden kasvuhäiriöt näyttävät liittyvän niiden ravinnetalouden tasapainottomuuteen: Tunnettujen pääravinteiden puutosoireita ei lueta kasvuhäiriöiksi. Kasvuhäiriöt johtavat puiden latvojen kuolemiseen ja puun laadun voimakkaaseen heikkenemiseen. Puista tulee oksaisia, mutkaisia tai monihaaraisia. Niiden käyttö sahatavarana ei ole mahdollista. Metsäntutkimuslaitoksella asiaa on tutkittu erityisprojektina prof. Olavi Huikarin johdolla vuodesta 1976 alkaen. Myös Norjassa ja Ruotsissa kasvuhäiriöillä on todettu olevan metsätaloudellisesti merkittäviä vaikutuksia ja niinpä siellä metsäntutkijat ovat kiinnostuneet asiasta. Suomessa eräät fyysikot ovat kiinnostuneet ongelmasta. Kasvuhäiriöihin liittyy tavallisesti lisääntynyt tautialttius ja lisäksi monet sienitaudit aiheuttavat lähes samanlaisia oireita kuin kasvuhäiriö. Aivan viime vuosina kasvuhäiriö on alkanut kiinnostaa myös metsäpuiden virusten tutkijoita.

Kokousta seuranneella retkeilyllä tutustuttiin Leivonmäen Kivisuon laajoihin lannoituskoekenttiin. Niissä voitiin nähdä männyn kasvuhäiriöitä ja sen aiheuttamaa puiden kuolemaa laajoilla alueilla.

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Helsinki 1983. Valtion painatuskeskus



Ransa Olavi Huikari

Dedicated to professor Olavi Huikari, the chief of the Peatland forestry department (1956—79) and the director of the Finnish Forest Research Institute since 1980, on his 60th birthday.

Professor Olavi Huikari, in addition to his important role in the mechanization of forest drainage and in starting experimental activity in peatland forest ecology, is one of the pioneers of the development of micro-and macronutrient fertilization experimentation on both research and practice in peatland forestry. He also started the study on the relationship between growth disturbances of forest trees and micronutrient nutrition already in the 1950's and the growth disturbance research project in 1976.

ACKNOWLEDGEMENTS

On behalf of the Finnish Forest Research Institute and the IUFRO Working Party S1.05—01 (Peatland Forestry) I have great pleasure in thanking all the participants and contributors who have made this Proceedings possible.

Professors Tauno Kallio and Eino Mälkönen have kindly read the manuscript and offered valuable criticism. Part of the drawings were made by Miss Anja Ripatti and the greatest burden of typewriting and compiling the manuscript was borne by Miss Maija Tuuri. The translation from Finnish into English was done by Mr. John Derome.

Many other persons, too, have helped me in my work. I extend my sincere thanks to them all and to the persons mentioned in the foregoing.

Helsinki, October 1983
Kimmo K. Kolari

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OPENING ADDRESSES

The Finnish Forest Research Institute has the great pleasure to wish you heartily welcome to the International Workshop on Growth Disturbances of Forest Trees.

The Finnish Forest Research Institute, together with IUFRO, considered that it would be of great benefit to invite experts in this field to a joint workshop in order to gain an overall picture of the problem of growth disturbances in forest trees. This would enable new information, new ideas and new developments in this field to be exhanged and discussed with the aim of finding solutions to the problem.

On behalf of the Finnish Forest Research Institute, I hope that this workshop will be both stimulating and rewarding for you all.

Olavi Huikari

The 17. World Congress of the International Union of Forestry Research Organizations was held last year in Kyoto, Japan. After that 43 Working Parties and 8 Project Groups in all have started their work in Division No. 1 dealing with the forest environmental and silvicultural questions.

One of the Working Parties in Division I is "Peatland forestry" which is concerned with the problems involved in the forestry utilization of organic soils. This Working Party, founded in Munich in 1967, was previously called "Afforestation of Peatlands and Extremely Wet Soils", but renamed in the Kyoto Congress to meet, better than before, the demands of practical activity and research scope.

So far, this Working Party has among other things made a report of drainage norms for peatland forests, and of investigations dealing with regeneration methods, a list of forest drainage terminology and a questionnaire dealing with the scope of ameliorative measures in practical forestry and experimental activity.

In the autumn of 1974 the first International Symposium on Forest Drainage was arranged in collaboration with the International Peat Society. Participants from 15 different countries numbered 102 in all. The second forest drainage symposium is being planned in the Soviet Union next year.

The present Symposium on Growth Disturbances is an essential sequel to the previous activity of "Peatland Forestry" Working Party. Growth disturbances observed in trees growing on peatland have already been discussed for instance in the Working Party meetings in Edinburgh in 1978 and in Hyytiälä, Finland in 1979. The meetings have emphasized the need for intensified research and exchange of information about the occurrence and prevention of growth disturbances. Finland, in particular, with her large areas of drained peatlands and growing problems with those disturbances in practical forestry, requires exchange of ideas with scientists from other countries representing different branches of knowledge. Now we have an excellent opportunity to do so during this meeting and the excursion.

On behalf of the "Peatland Forestry" Working Party of IUFRO which is the other organizer for this Symposium on Growth Disturbances, I heartily welcome all the participants to this symposium and wish success to its work.

Eero Paavilainen

SESSION 1.

GROWTH DISTURBANCES OF FOREST TREES

HISTORY OF GROWTH DISTURBANCE RESEARCH IN FINLAND

Olavi Huikari

Forest research in all countries is based on observation of the external appearance of trees. The so-called normal appearance of different tree species has been the starting point for research and practical forestry measures right from the very beginning.

The external appearance of all species is determined by the genetic properties, the final form being affected to a varying degree by external factors.

At least 5 million ha of poorly-productive peatlands have been drained for forestry purposes in Finland during the past 50 years. Following the results of this work has entailed careful measurement and observation so as to determine changes in the water status of the peat substrate and the effect of nutrient changes associated with this. Analysis of the factors limiting growth was started in the 1950s. Development of the stands in the vast majority of the drained areas went according to the results obtained from field experiments. At the same time, however, it was noticed that in a number of exceptions, such as bogs with a thick peat layer or very many rimpis, the growth of the tree stand showed considerable local variation and, after an initial good start, rapidly became checked. I started studying this phenomenon at Kaakkosuo, Vilppula, in 1950 and published the first results in Suolehti N:o 1 1951 under the title "Observations on the factors preventing seedling formation on drained rimpi open bogs". At the same time I established a series of micronutrient fertilization experiments at Vilppula, at Haapavesi and at Kivalo in the district of Rovaniemi. It soon became apparent that fertilization with wood ash brought about a recovery in stands growth and that the growth disturbances, which started with the dieback of the leaders, were completely cured. Later on, a number of studies were carried out in this question and the results published. In the

1970s, the Finnish Forest Research Institute established a separate research project to study growth disturbances in forest trees.

The growth disturbance research project has proceeded systematically by separating out the cause and effect relationships in the different changes in external appearance of the tree. The presence of insect and fungal damage has always been first checked and usually been found to be secondary causes.

We are now at the stage as far as our knowledge of the subject is concerned, where it is no longer necessary to report old data, but instead can concentrate on examining the results of more recent experiments.

There is much data available throughout the world in the question of growth disturbances in trees and it would be of great benefit to use this occasion to collect it together for the use of all. It is not a question of a subject which will suddenly change forestry in the world, but the representatives of forest research and practical forestry should be made aware of the factors which affect tree growth and of all means which can be used to rectify such a situation. Forestation of eroded grasslands and vast open peatlands may be fraught with considerable difficulties. However, the results obtained so far indicate that these can be overcome.

EARLY OBSERVATIONS ON DIE-BACK OF SCOTS PINE IN THE FERTILIZATION EXPERIMENTS AT KIVISUO

Timo Kurkela

The first disease survey was made in Experiment I at Kivisuo in 1964, four years after the beginning of the experiment. In addition to snow blight and winter drought, die-back disease on Scots pine, whose cause could not be determined at that time, was also observed. This type of die-back, or growth disturbance, according to present knowledge, is caused by micronutrient deficiency. Although not important for the development of the stands, its appearance at Kivisuo was interesting.

The percentage of die-back diseased pines varied among experimental plots from about 1 to 5,5 %. The only fertilizer (of the nitrogen, phosphorus, and posassium used) affecting this phenomenon was potassium, which increased it significantly.

It is possible that potassium fertilization causes a greater need for micronutrients and under certain external conditions (e.g. weather), the pine is not able to uptake enough of them. When external factors again become more favourable, this type of die-back may dissappear for many years, as happened in Kivisuo.

Introduction

The first forest fertilization experiments at Kivisuo, Leivonmäki, Central Finland, were established by the Finnish Forest Research Institute in 1959. Some harmful phenomena were observed at the experimental sites in 1963. To find their distribution under different treatments and to determine their nature, the first surveys were made in the summer of the following year, 1964. Both at that time and later, the major



Figure 1. A pine with recently killed leader shoot in Experiment I at Kivisuo in the spring of 1964. No new leader are as yet visible.



Figure 2. A pine with die-back in the leader shoot grown in 1962. Numerous adventitious shoots are developing in the internode of 1961. Branches in the lower whorl have taken the leader role.

disease of Scots pine was snow blight (*Phacidium infestans* Karst.) (Kurkela 1965, 1975). Another serious phenomenon for pines was needle browning caused by winter drought (Reinikainen 1967), which resulted in die-back of pines on experimental plots lacking phosphorus treatment (Kurkela 1979). To a lesser extent there also appeared another type of die-back, the nature of which was not fully understood, but which was not threatening the stand development at that time.

In respect to the knowledge accumulated during recent years about growth disturbances in connection with micronutrient deficiencies (Raitio and Rantala 1977, Raitio 1979, Kolari 1979, Kurkela 1981), the data collected in 1964 on that minor die-back at Kivisuo are examined in this paper.

Description of the die-back

Most of the diseased trees had been growing well. The length of the last, killed leader shoot varied, but it was usually very sturdy. The uppermost needles could also be long and broad. Often, the number of buds was exceptionally high. Dying started from the buds and extended diffusedly downwards. The first symptoms of die-back during the spring were a slight yellowing of the uppermost needles, which also were projected and out of the natural order (Fig. 1). Pines tended to form a new leader from the same or one year older branch whorl (Fig. 2).

Pycnidia of *Gremmeniella abietina* Morelet were found, or its mycelium was isolated from, about 25 % of the diseased

shoots. *Sclerophoma pityophila* (Corda) v. Höhn. and *Scoleconectria cucurbitula* (Tode ex. Fr.) Booth were also commonly found on dead shoots. *G. abietina* is known as a primary pathogen causing die-back in pines. It might have some role in shoot killing at Kivisuo too, although the diffused spread of dying tissue did not suggest fungi or bacteria as the primary cause.

Material and method

The data were collected from Experiment I at Kivisuo during the summer of 1964. The experiment has been described earlier in several papers, e.g. Huikari and Paarlahti (1966). The fertilizers (N, P and K), were broadcast and given at four levels of each fertilizer. The experiment had a fully combined factorial design. About 220 pine transplants were planted per experimental plot. Some mortality caused by weed growth, especially in the plots having a high level of nitrogen (400 kg/ha of N) and potassium (200 kg/ha of K_2O) fertilization, had decreased the number of plants to about 60.

All living pines were examined. Die-back was counted in the whorles of 1962 and 1963. It did not appear in the whorl of 1964 at the time of survey. If a pine had dead shoots in both whorles, its stress in the data was doubled. The percent of die-back for each plot and treatment combination was calculated. Because winter drought resulted in die-back in the plots without phosphorus fertilization, these plots were omitted from the data. The statistical significance of the treatment effects was studied with an analysis of variance.

Results and discussion

The average percentage of die-back in the whole experiment was about 3 %. The fertilizers had different effects: N increased slightly, while P seemed to decrease, the disease. Neither of these effects was significant, however. The effect of K was clearly different: K increased die-back significantly ($P < 0{,}001$). The average die-back incidence at zero level of K was about 1 %, and K-fertilization increased the incidence in almost a straight line up to 5,5 % at the level of 200 kg/ha of K_2O (Fig. 3).

Although the effect of K-fertilization was not quite parallel at the different N- and P-levels, there was no statistically significant interaction of fertilizers.

Usually, nutritional growth disturbance appears in pine stands on fertilized peatlands 8—10 years after the fertilization. Several exceptions from that have also been observed. A great deal of evidence has accumulated in recent years to support the theory that primary cause of die-back in growth disturbance is deficiency of micronutrients (Kolari 1979). Some other factors may also be important, e.g. soil and weather conditions (Kosonen and Silfverberg 1976, Silfverberg 1979). According to Braekke (1979), die-back is more serious in Norway spruces which were not fertilized with copper and boron than in those so fertilized, on a site with a high frequency of frost damage. Boron deficiency, which lowers the cold hardiness of pines, may make them more susceptible to *Gremmeniella abietina* (cfr. Dietrichson 1968). It could be possible that K-fertilization caused a greater need of micronutrients in pines which, under the special conditions at Kivisuo, were not able to fill this requirement by uptake. Apparently, conditions became more favourable at Kivisuo after 1964, because this type of die-back disappeared for several years.

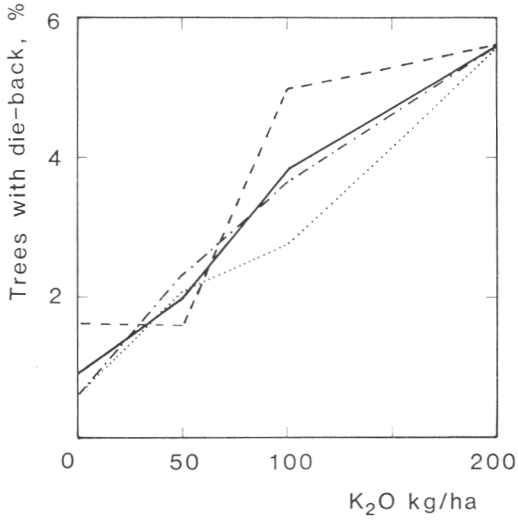


Figure 3. The relation between leader shoot die-back of Scots pine and potassium fertilization in Experiment I at Kivisuo in 1964. The different lines represent different levels of phosphorus fertilization: --- = 66, -·-·- = 132, and ····· = 198 kg/ha of P_2O_5; ——— = average effect of K_2O.

References

BRAEKKE. F. H. 1979. Boron deficiency in forest plantations on peatland in Norway. Medd. Nor. inst. skogforsk. 35: 213—236.

DIETRICHSON, J. 1968. Provenance and resistance to *Scleroderris lagerbergii* Gremmen (*Crumenula abietina* Lagerb.). The international Scots pine provenance experiment of 1938 at Matrand. Medd. norske Skogforsøksvaesen 25:395—410.

HUIKARI, O. & PAARLAHTI, K. 1966. Kivisuon metsänlannoituskokeet, kenttäopas. Helsinki.

KOLARI, K. K. 1979. Hivenravinteiden puute metsäpuilla ja männyn kasvuhäiriöilmiö Suomessa. Kirjallisuuskatsaus. Abstract: Micronutrient deficiency in forest trees and die-back of Scots pine in Finland. A review. Folia For. 389: 1—37.

KOSONEN, R. & SILFVERBERG, K. 1976. Havaintoja eskimosis-ilmiöstä männyllä Kivisuolla 1976. Metsäntutkimuslaitoksen suontutkimusosaston tiedonantoja 8/1976:1—15.

KURKELA, T. 1965. Männyn lumikaristetaudin ja lannoituksen suhteesta Kivisuon metsänlannoitusalueella. Summary: On the relationship between the snow blight (*Phacidium infestans* Karst.) and fertilization in Scots pine seedlings. Folia For. 14:1—8.

— 1975. Incidence of snow blight on Scots pine as affected by fertilization and some environmental factors. Seloste: Lannoituksen ja eräiden ympäristötekijäin vaikutuksesta männyn tainten lumikaristeisuuteen. Commun. Inst. For. Fenn. 85.2: 1—35.

— 1979. Effect of fertilization on winter drying of Scots pine. Proc. IUFRO Seminar Mountain Forests and Avalanches, Davos, 1978, pp. 139—143.

— 1981. Versosyöpä (*Gremmeniella abietina*) riukuasteen männiköissä. Summary: Canker and die-back of Scots pine at precommercial stage caused by *Gremmeniella abietina*. Folia For. 485: 1—12.

RAITIO, H. 1979. Boorin puutteesta aiheutuva männyn kasvuhäiriö metsitetyllä suopellolla. Abstract: Growth disturbances of Scots pine caused by boron deficiency on an afforested abandoned peatland field. Folia For. 412:1—16.

RAITIO, H & RANTALA, E.-M. 1977. Männyn kasvuhäiriön makro- ja mikroskooppisia oireita. Oireiden kuvaus ja tulkinta. Summary: Macroscopic and microscopic symptoms of a growth disturbance on Scots pine. Description and interpretation. Commun. Inst. For. Fenn. 91.1:1—30.

REINIKAINEN, A. 1967. The appearance of nutrient deficiency in plants growing in the experimental area for forest fertilization at Kivisuo. Forest Fertilization. Proc. 5th Colloq. Int. Potash Inst., Jyväskylä, Finland, pp. 39—40.

SILFVERBERG, K. 1979. Männyn kasvuhäiriön alkukehitys ja ajoittuminen turvemaan hivenpuutosalueella. Abstract. Phenology and initial development of a growth disorder in Scots pine on boron deficient peatland. Folia For. 396:1—19.

Total of 13 references

GEOGRAPHICAL DISTRIBUTION OF GROWTH DISTURBANCES IN FINLAND

Heikki Veijalainen

In 1976 283 observations of growth disturbances in forest stands from 130 municipalities were recorded. In 1981 the listed number of growth disturbance areas exceeded 400. More than 2/3 of them were in pine stands, usually on drained peatland. The total area of growth disturbance stands is roughly 2 % of the drained area i.e. 100 000 ha. Less than 15 % of the observations are from mineral soil sites. Preliminary results of a systematic study from southern Finland are discussed.

Growth disturbance areas vary usually between 1—8 hectares in size. The mean height of the stands is usually 3—8 meters. Growth disturbances occur in all parts of Finland, but a clear concentration has been observed in Central Finland and in northern Ostrobothnia.

Introduction

Finland is almost totally covered by forests. Unforested areas occur in the northernmost parts of Lapland and in western and southern Finland, where our most extensive agricultural areas are situated. The area of forested land totals 21,9 million ha excluding forest waste land (4,5 million ha). Mineral soil constitutes 65 % and peatlands 35 % of the forest land. The area of drained peatlands amounts to 5,5 million ha (Yearbook of Forest Statistics 1981).

The first reports of growth disturbances and micronutrient fertilizer experiments carried out on peatlands in Finland date back to the early 1950's. At that time patchy areas of poor tree growth and total failures in the afforestation of some drained rimpi-fens were reported (Huikari 1951). Later on disorder symptoms were reported in pine, spruce and birch stands (Huikari 1974, Veijalainen 1974, 1975) growing on both mineral soil and peatland sites. The hypothesis that micronutrient deficiencies were the causal agents was put forward by Huikari (1974).

The purpose of this series of studies was to gain a rough estimate of the extent of growth disturbances and to throw light upon its geographical distribution in Finland.

Material and methods

Three different methods were used in collecting information about growth disturbance areas.

1. A questionnaire study in 1976 (Veijalainen 1978). Questionnaires were posted to 522 persons who had received a proper forestry education and who, during their routine work, were able to inspect young afforestation areas in their own areas. The questionnaires were sent out at a time when the state grants for the tending of young plantations had just been released. 452 questionnaire forms were returned. 35 randomly sampled observations were immediately checked by specialists. All the pine stands examined showed typical growth disturbance symptoms. Frost damage and damage caused by *Thekopsora areolata (Fr.) Magn.* and other fungal diseases caused confusion in the spruce stands so that such observations must be treated with caution. None of the birch observations were checked.
2. During the period 1976—81, new reports of growth disturbance areas have been listed as soon as forest owners of forestry people have informed us about them. In many cases the information has been checked by researchers.
3. A systematic study of "multiple leaders" has been included in the 7th National Forest Inventory (1977—84). Altogether about 9000 sample plots will be inspected. In this phase we have a systematic material from southern Finland only. Sample plots are relascope plots and each sample tree has its own number. The checking work is thus quite easy. About 20 % of the disturbed sample plots in southern Finland have been checked as well as some plots which have been unaffected. The ratio between incorrect and correct observations has been used in calculating the final number of growth disturbance areas in this sub-study.

Results

The questionnaire study revealed 283 growth disturbance areas in 130 different districts. Most of the observations were from the northern Ostrobothnia. Kainuu and Central Finland forestry board districts, all of which are very rich in peatlands. Only a few observations came from the Helsinki and Vaasa forestry board districts (southern and western coasts). It seems that there are no great problems in pine stands in northern Lapland and in the southernmost parts of Finland (Fig. 1).

The returned questionnaires contained areal information about 235 disturbed stands only. 91,5 % of the disturbed areas were smaller in size than 15 ha. The typical size of a disturbed area ranged from 1—8



Figure 1. Distribution of growth disturbances in Scots pine stands in Finland 1976—80.

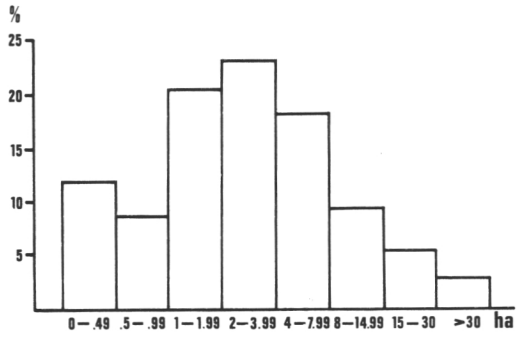


Figure 2. Frequency of growth disturbance observations in different area classes, all tree species.

hectares (Fig. 2). The most extensive areas were 30—100 ha in size.

Most of the observations came from ditched peatland sites (51,3 %). Only 22,6 % were from mineral soil sites and 19,4 % from afforested agricultural land (81,5 % peat soils). 6,7 % of the observations contained no information about the site. No observations came from unditched peatlands, where die-back in birch, especially, seems to appear frequently. However, 75,4 % of the observations came from peatlands, the areas affected apparently being larger than in the case with mineral soils. The areal percentages were as follows:

Ditched peatlands	44,0 %
Afforested agricultural land	50,8 "
Mineral forest soil	5,2 "

On the mineral soil sites, more than 64 % of the observations were on site types better than VT (*Vaccinium*-type) and also on the peatlands growth disturbances were mostly on minerotrophic and mesotrophic sites. Only 3,5 % of the observations were reported on *Sphagnum-fuscum* sites (Huikari et al 1963).

Pine (*Pinus sylvestris*) was the dominating tree species in 66,8 %, spruce (*Picea abies*) in 15,3 % and birch (*Betula pendula* or *B. pubescens*) in 3,7 % of the observations. On ditched peatlands pine was dominating in 87,7 %, on afforested agricultural land 80,4 % and on mineral forest soils 55,0 % of the observations.

The spruce dominated disturbance areas were mainly on mineral soils (65 %) and, furthermore, in most cases located in southern or south-eastern Finland. The first checking tours revealed that all the pine observations had been correctly diagnosed. In many cases birches, spruces and *Salix*-species, even *Juniperus communis*, showed die-back symptoms in mixed stands or growing under the dominating pine stands.

The mean height of the dominating trees was 3—8 m in 58 % of the cases, less than 2 m in 22 % and more than 8 m in 20 % of the stands for which there was information available (n = 212). Die-backs were very seldom reported from stands exceeding 10 m in height.

Only 123 observations included information about fertilization. 85 % of these stands had been fertilized, 75 % using PK- or NPK-fertilization and 10 % using single macronutrients. The unfertilized growth disturbance areas were in all cases rather fertile sites.

It is evident that this study does not give a full account of all the growth disturbance areas in Finland. The total growth disturbance area at that time was estimated to be more than 20 000 ha (Veijalainen 1978).

The material collected from forest owners etc., has brought to light more than 100 new localities with severe die-backs and new observations are coming in monthly. Only in very few cases have the forest owners been mistaken, usually because they are not familiar with the symptoms of phosphorus or potassium deficiency. Sometimes fertilization shock or summer flooding damage have been reported as growth disturbances since the symptoms are very similar.

The systematic study conducted as a part of the 7th National Forest Inventory has provided us with 115 stands containing trees with dry or multiple apical shoots. A sample of 30 % of these observations has already been checked in southern Finland. We have estimated that these reports cover 20 new growth disturbance areas. This has led us to make a new estimate for the whole country. Nowadays we are quite sure that more than 100 000 ha of forest land has been affected in Finland by different visible growth disturbances and, in addition, invisible or latent disorders in trees are supposed to be quite general in growth disturbance areas and in their surroundings.

Discussion

No earlier investigations have been conducted in this field in Finland. According to Prof. Heikurainen, growth disturbances have been observed on some unditched minerotrophic mires. Vast draining operations were started in Finland in the 1960's and more than 100 000 ha of different types of peatland were ditched annually. It was not possible during this phase of extensive forest amelioration work to select the ditching objects very accurately or to pick out unsuitable small peatland plots. On the other hand, there was no scientific data available at that time about growth disturbances. However, ditching operations were conducted at a time when energy was cheap, and therefore the total area of growth disturbances does not nullify the forest drainage investments when looked at from the national level. In individual cases, however, some private forest owners have suffered severe financial losses.

It is obvious that in the near future we will be talking about micronutrient deficiencies, harmful flooding effects or macronutrient shock and a more detailed picture of their geographical distribution will be necessary. We must also keep in mind that the situation will never remain static.

According to Tolonen (1974), boron concentrations in the water lying in hollows on ombrotrophic raised bogs are highest in the coastal regions of southern Finland (Fig. 1). This negative geographical correlation between growth disturbances and rain water quality may explain why peatlands in the southern parts are almost completely free of growth disturbances. The northern parts of the Gulf of Bothnia are covered by ice during the start of the growing period. This may explain why growth disturbances have frequently been observed in the immediate vicinity of the north-western coast. In northern Finland only a small number of peatlands have been ditched and fertilized to date. This fact may explain to some extent the lack of observations in the north.

Peatlands are usually poor in phosphorus, potassium and sometimes in available nitrogen, too. Consequently, more complicated and efficient fertilization treatments are necessary there than on mineral soil sites. Furthermore, the root system of trees growing on peatlands are very superficial. This may be one reason for the relative anomaly of growth disturbances on mineral soil sites.

Literature

HUIKARI, O. 1951. Havaintoja ojitettujen rimpinevojen taimettumista ehkäisevistä tekijöistä. Suo 2(1):1—4.

— 1974. Hivenravinteet ja puiden kasvu. Metsä ja Puu 11:28—29.

— MUOTIALA, S, & WÄRE, M. 1963. Ojitusopas. 244 p. Kirjayhtymä. Helsinki.

TOLONEN, K. 1974. Suomen keidassuovesien ravinteista. Summary: On the nutrient content of surface water in ombrotrophic mire complexes in Finland. Suo 25(3—4):41—51.

VEIJALAINEN, H. 1974. Makro- ja mikrolannoituskoe kuusen "eskimoosis"-alueella. Metsäntutkimuslaitoksen suontutkimusosaston tiedonantoja 6/1974. 8 s.

— 1975. Kasvuhäiriöistä ja niiden syistä metsäojitusalueilla. Summary: Die-back and fertilization on drained peatlands. Suo 26(5):87—92.

— 1978. Metsäpuiden latvakadon esiintymisestä Suomessa. Summary: Occurrence of die-back of forest trees in Finland. Metsäntutkimuslaitoksen suontutkimusosaston tiedonantoja 1/1978: 1—22.

Yearbook of forest statistics 1981. Official statistics of Finland XVII A:13. Folia For. 510. 214 p.

Total of 8 references

GROWTH DISTURBANCES IN NURSERY-GROWN PINE SEEDLINGS

Hannu Raitio

Since the end of the 1970s growth disturbances were found in our nurseries, especially in bare-rooted pine seedlings grown unsheltered. The disturbances are characterized by the death of apexes, which makes a number of new lateral buds open. In the end there is a multiple-leader, bushy seedling, which had ceased to grow taller. The phenomenon is only rarely found to any extent in pine seedlings grown in plastic houses, where it has been encountered only in few individuals. Disturbances of this kind have so far been detected only in nursery-grown pine seedlings.

The growth disturbances are already seen in one-year-old seedlings grown unsheltered. They usually appear in seedling individuals or in small seedling groups. In the worst cases all the seedlings are affected. Abnormal individuals are clearly distinguishable from normal seedlings by their shorter height. The seed bed with growth disturbances has usually had poor germinability i.e. the seedlings are far apart from each other. At a later stage in transplanted areas, unevensized seedlings reveal the existence of growth disturbances.

The disturbance is usually seen a few weeks after germination. Then an appearance of necrotic cells at the apex indicates the death of the apex. The death of the apex not only stops height growth but also leads to the opening of new lateral buds. Thus the seedlings will have several equally strong shoots competing for the leader position during growing period. As this recurs in the following years, the result is a multiple-leader seedling. Obviously the nursery-grown seedlings have difficulties in finding the normal apical dominance if the apex dies in the first growing season. If the seedling survives, it may, years after being planted in a forest, succeed in finding its apical dominance.

The needles of affected one- and two-year-old seedlings are long, dark green variously twisted. In two-year-old and older seedlings onwards the most important microscopic symptoms are the overgrowth of cells, dissarrangement of cell tissue and formation of cavities.

The macroscopic and microscopic symptoms of abnormal seedlings greatly resemble the earlier observed symptoms in pine plantations (see Raitio & Rantala 1977, Raitio 1979, 1981). The symptoms, according to the observations so far, indicate both boron and molybdenum shortage (see Bergmann & Neubert 1976, Kolari 1979), although the interpretation of symptoms alone is difficult, as the deficiency and toxication symptoms of micronutrients resemble each other. The nature and symptoms of the phenomenon refer, however, to a nutritional imbalance and possible micronutrient deficiencies. The comparative nutrient analyses have shown, as is seen in Table 1, that the affected seedlings have above all high iron contents. Usually also the contents of the main nutrients, especially nitrogen, have been suspiciously high (see Raitio & Rikala 1981). In some cases the manganese contents have also been quite high.

The substrate in nurseries, where growth disturbance is a serious problem, is composed of soil fractions of medium sand or fine sand with relatively little organic matter (Table 2). In such conditions the water regime may change rapidly. The pH of the substrate is around 4,0 in these nurseries.

According to preliminary nutrient analyses it seems, however, that growth disturbances in nurseries are not at any rate caused by an absolute boron shortage. Neither did the preliminary boron fertilization experiments at the Juuka nursery in the summer of 1982 improve the situation sufficiently.

Table 1. Nutrient contents of one-year-old pine seedlings in some nurseries in autumn 1982.

Nursery	Origin	Sampling time	Disturbance degree	N %	P mg/g	K mg/g	Ca mg/g	Mg mg/g	Fe ppm	B ppm	Cu ppm	Zn ppm	Mn ppm	Mo ppm	Al ppm
Keuruu	Konginkangas	16. 9. 82	Healthy	2.42	2.80	10.4	1.46	1.22	82	23.7	7.3	52	606	—	—
Alakärppä	Ylitornio	16. 9. 82	"Healthy-looking"	2.96	3.06	11.1	0.90	1.10	101	21.1	7.0	61	628	—	—
Patama	Herrasenaho	16. 9. 82	"Healthy-looking"	2.74	2.86	13.4	1.20	0.87	289	17.6	11.5	87	344	—	—
"	"	16. 9. 82	Poor	2.76	2.79	13.0	1.42	0.93	506	18.7	11.2	98	322	—	—
Juuka	Juuka	13. 9. 82	Poor	2.50	3.07	12.2	2.19	1.22	272	51.7[1)]	10.8	171	901	—	—
Naturally regenerated seedlings, Karvia. *Vaccinium* site type, July 27, 1982. High occurrence of growth disturbances. The analyzed seedlings 'healthy-looking'				1.54	1.95	6.7	1.71	0.97	31.6	9.5	5.5	43.2	158	below 0.025	263

[1)] Fertilized with natrium polyborate in summer 1982.

Table 2. Particle size composition % at the nurseries of Alakärppä (Oulu) and Juuka.

Nursery	Organic matter	> 2.0 mm	2.0—0.6 mm	Ø 0.6—0.2 mm	0.2—0.06 mm	< 0.06 mm
Alakärppä						
Palosuo	3.73	0.51	11.69	58.92	23.11	2.04
Aalikko	3.47	0.67	3.22	68.96	22.33	1.35
Juuka						
Block 24	3.35	0.39	1.74	10.72	73.73	10.07
Block 2	3.42	0.77	1.38	29.98	58.82	5.63

Comparative nutrient analyses with molybdenum have not been made so far. Several investigations have shown that the high contents of iron, aluminum and manganese have made it difficult for the plants to take molybdenum. Similarly, drought impedes the uptake of molybdenum. Problems with the water regime in nurseries may result from the poor physical structure of soil and/or the structural changes in plant roots — too low root/shoot ratio, weak formation of mycorrhizas, anatomy of roots damaged. The sulphate fertilizers used in nurseries may also impede the uptake of molybdenum by plants, as the sulphate ion competes with molybdenum. Sulphate lowers soil pH, decreasing the availability of molybdenum. The uptake of molybdenum is lowest at pH 4 (Bergman & Neubert 1976, Mengel & Kirkby 1979, Amberger 1979).

The growth disturbance symptoms, the physical and chemical properties of nursery soil and the comparative nutrient analyses imply that growth disturbances would be caused by either boron or molybdenum shortage. The shortage is not necessarily absolute, but the result on the one hand from high contents of nitrogen, iron, aluminum, manganese and sulphate and on the other hand rapid changes in the water regime. This is also a possible explanation for growth disturbances in mineral soil (Fig. 1).

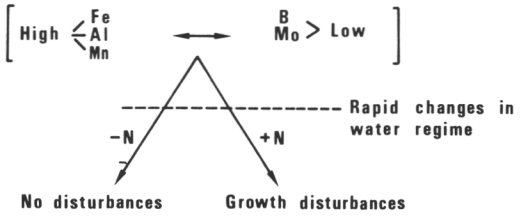


Figure 1. Hypothetical scheme of the process of growth disturbances.

The number of multiple-leader seedlings can be reduced by selection at the transplanting stage. They cannot, however, be completely eliminated as also the healthy-looking seedlings in these seed beds are more or less affected. Thus after transplanting the disturbance may break out. If completely healthy seedlings are transplanted on problematic area, the disturbance does not appear at all at nursery stage, but may break out in the first few years after planting in a forest. By adding undecomposed *Sphagnum* peat to the substrate and by lowering fertilizer rates promising results have been obtained in practice.

Literature

AMBERGER, A. 1979. Pflanzenernährung. 237 s. Stuttgart. Eugen Ulmer GmbH & Co.

BERGMANN, W. &. NEUBERT, P. 1976. Pflanzendiagnose und Pflanzenanalyse zur Ermittlung von Ernährungsstörungen und des Ernährungszustandes der Kulturpflanzen. 711 s. Jena. Gustav Fischer Verlag.

MENGEL, K. & KIRKBY, E. A. 1979. Principles of plant nutrition 593, s, Bern. International Potash Institute.

RAITIO, H. 1979. Boorin puutteesta aiheutuva männyn kasvuhäiriö metsitetyllä suopellolla. Oireiden kuvaus ja tulkinta. Summary: Growth disturbances of Scots pine caused by boron deficiency on an afforested abandoned peatland field. Description and interpretation of symptoms. Folia For. 412:1—16.

— 1981. Pääravinnelannoituksen vaikutus männyn neulasten rakenteeseen ja ravinnepitoisuuksiin ojitetulla lyhytkorsinevalla. Abstract: Effect of macronutrient fertilization on the structure and nutrient content of pine needles on a drained short sedge bog. Folia For. 456:1—10.

— & RANTALA, E.-M. 1977. Männyn kasvuhäiriön makro- ja mikroskooppisia oireita. Oireiden kuvaus ja tulkinta. Summary: Macroscopic and microscopic symptoms of a growth disturbance in Scots pine. Description and interpretation. Commun. Inst. For Fenn. 91(1):1—29.

— & RIKALA, R. 1981. Näkökohtia taimien ravinnetaloudesta ja lannoituksesta taimitarhalla. Metsäntutkimuslaitoksen tiedonantoja 15:1—28.

Total of 7 references

OCCURRENCE OF GROWTH DISTURBANCE PROBLEMS IN NORWEGIAN AND SWEDISH FORESTRY

Finn H. Brække

The discussion on growth disturbances is limited to micronutrient deficiency problems in Fennoscandian forests. Disturbances of this type are unusual in natural boreal forests, probably because trees primarily are restricted in growth by nitrogen on mineral soil, and by phosphorus and a high water table level on organic soils.

Growth disturbances on peatland in Norway were first observed in the 1950's. Young plantations of conifers were frequently damaged by radiation frost in the growing season, and in late autumn or winter apical shoots were often hurt. In older trees "shoot die-back" has been a characteristic symptom.

Boron deficiency turned out to be a reason for these problems, which occur on afforested peatland throughout Norway except for a 20—60 km broad coastal belt. Fertilization with PK or NPK inside this belt, obviously induces boron deficiency.

Systematic research on possible micronutrient deficiencies in mineral soil forests is not done. However, growth disorders indicating boron deficiency, are reported after application of high doses of N-fertilizer.

Peatland forests in Sweden are not studied systematically with respect to micronutrient deficiencies. Possible boron deficiency on mineral soil are reported for young stands of Scots pine after intensive N-fertilization at one-year-interval. Liming in addition to N, seems to increase the growth disorder problems.

A regional pilot study in Scots pine forests on mineral soil in Sweden indicates that repeated fertilizations (5-year-intervals) with doses common in practical forestry (150 kg N/ha), reduced boron contents in foliage. In some regions it fell below critical level (< 3 ppm B), and "shoot die-back" has occurred. It is likely that potential boron deficiency is mainly restricted to areas inside the marine lowland sediments which mean above marine limit in Norrland, Svealand and probably also Götaland.

Introduction

Growth disturbances in forest trees can be caused by many factors. The discussion here will be limited to micronurient deficiency problems in Fennoscandian forests.

When cycling of nutrients is not manipulated by drainage, fertilizers, air pollution, full tree harvesting etc., micronutrient deficiencies are rather uncommon in boreal forests. A possible low supply of micronutrients under natural conditions will usually be hidden because growth of trees primarily are restricted by nitrogen on mineral soils, and by phosphorus combined with waterlogged root zone on peatland.

Disturbance problems on peatland in Norway

Induced growth disturbance problems in peatland plantations were first observed in the 1950's. Unlignified shoots of young *Picea abies* were frequently damaged by radiation frost in the growing season (Meshechok, 1968). In late autumn and during the dormant season not properly hardened apical shoots of Norway spruce were often killed by freezing or drying out. Severety of frost often increased with age of plantations, and some of these were completely damaged before reaching breast height.

In other cases young stands showed excellent growth for 10 to 18 years when "shoot die-back" suddenly developed. Water stress probably released this type of damage. "Shoot die-back" is so far being studied for *Picea abies* (L.) Karst., *Pinus sylvestris* L., *P. contorta* ssp. *latifolia* Dougl. and *Betula* spp. mostly *B. pubescens* Ehrh.

Boron deficiency turned out to be the main physiological factor behind these problems, which occur frequently on afforested peatland in Norway except for a 20—60 km broad coastal belt. Drainage and fertilization with PK or NPK inside this belt, obviously induced boron deficiencies (Brække, 1977, 1979, 1980).

Deficiencies disturb the apical dominance of trees, but it is reason to expect that root system is also hurt. Despite great loss of vitality, such trees usually keep their recovery potentials for some time. It is rather common that trees which suddenly develop boron deficiency due to temporary water stress, recover to normal growth again after some years with climatic and edaphic stress at low intensities.

Growth disturbances caused by inadequate boron uptake are both genetically and species dependent. On fields with such problems strong selection seems to take place. Some trees survive and grow excellent at rather low boron supply while neighbour trees are dead or dying from boron deficiencies. It is common experience that *Pinus contorta* ssp. *latifolia* is less susceptible to low boron supply than *Picea abies* and *Pinus sylvestris* (Brække, 1982).

Systematic research on possible micronutrient deficiencies in forests on mineral soil is not done. However, growth disorders indicating boron deficiency, are reported after application of high doses of N-fertilizer to Scots pine stands on inland sites.

Disturbance problems in Sweden

Peatland forests in Sweden are not studied systematically with respect to potentials for micronutrient deficiencies. Boron deficiencies on mineral soil are reported for young Scots pine stands after intensive N-fertilizations at one-year-interval. Additional liming seems to increase the growth disorder problems (Aronsson, 1980; Burgtorf, 1981).

After the very dry years of 1975—76 extensive "sub top dying" was registered for *Picea abies* in Svealand and Götaland (Barklund et al. 1977, Aronsson et al. 1978). It was concluded that the damage had been released by successive droughts in the previous years. However, there are still open questions to these problems, and possible interactions to inadequate macro- and/or micronutrient supply were not discussed in detail. Aronsson et al. (1978), for example, mentioned that damage forest on low lying grounds at Hjälmaren in Svealand also had potassium deficiency.

It is well documented that availability and/or uptake rate for boron is reduced in periods with droughts, sometimes drastically. Although a series of interactions may have occurred when "the sub top dying" developed, there is reason to expect that boron deficiencies could have played a role on some of the inland sites, especially on sites with a normal high water table level.

A regional pilot study in forests on mineral soil in Sweden indicates that repeated fertilizations (5-years-intervals) with N-doses used in commercial forestry (150 kg N/ha), have reduced boron contents in Scots pine foliage. In some regions it has fallen below critical level (< 3 ppm B), and "shoot die-back" has occurred (pers. comm. G. Möller, 1982). It is likely that potential boron deficiency on mineral soils in Sweden is mainly restricted to areas inside the marine lowland sediments which mean forested land above marine limit in Norrland, Svealand, and Götaland. Sandy soils low in organic matter, poor fens and bogs may as well have low boron contents in root zone below the marine limit.

Updated status on forest boron deficiencies

Boron deficiencies in Norwegian and Swedish forestry are more common than previously thought. We must admit that we still know too little about this problem, but we do have significant results which show that various kinds of human impacts on forest ecosystems have induced boron deficiencies.

Table 1. Fertilized stands on peat soils in Norway with low needle boron contents and growth disturbances.

Site	Latitude North	B ppm		Reference
		Norway spruce	Scots pine	
1. Støfloen	64°27'	3.2	9.9	Brække (1979)
2. Nessimyra	63°21'	—	—	
3. Helakmyra	61°41'	—	—	
4. Malmmyra	61°38'	1.8	6.9	Brække (1979)
5. Almyra	61°22'	2.4	—	" "
6. Prestsætermyra	61°05'	1.9	5.7	" "
7. Guritjernsmyr	61°05'	—	—	" "
8. Kindlistormyra	61°05'	—	—	" "
9. Tranbærmyra	61°01'	2.2	5.4	" "
10. Tranmyra	60°57'	—	—	
11. Jengårdsmyra	60°55'	—	—	
12. Øytjernsmyra	60°51'	2.1	5.2	Brække (1979)
13. Stangstumyra	60°47'	1.8	2.8	" "
14. Svarttjernsmyra	60°47'	—	—	
15. Kjølamyra	60°37'	1.5	4.9	Brække (1979)
16. Lensmannsmyra	60°36'	1.6	4.3	" "
17. Njustmyra	60°17'	1.4	1.0	Brække (1977)
18. Kultemyra	60°12'	3.4	—	Brække (1982)
19. Damtjernsmyra	60°10'	—	—	
20. Skøyenmyra	60°02'	3.3	3.6	Brække (1979)
21. Glomsmyra	59°57'	—	4.3	" "
22. Setermosen	59°46'	4.4	—	" "
23. Breimyra	59°24'	2.5	7.8	" "
24. Gongemyra	59°15'	2.4	2.6	" "
25. Blautmyra	58°50'	—	—	
26. Riislandsmyra	58°45'	2.3	2.8	Brække (1979)
27. Gjerbrumyra	58°33'	4.7	6.5	" "
1.—27. Range	64°27'—58°33'	4.7—1.4	9.9—1.0	
Mean		2.5	4.9	

Table 2. Fertilized Scots pine stands with low needle boron contents and growth disturbances on mineral soils in Sweden.

Site		Latitude North	B ppm	Reference
1. 728	Själlarimsheden	ca. 66°30'	2.7 — 2.0	Burgtorf (1981)
2. 1	Vuollerim	66°22'	3.9	Möller (1982) pers.comm.
3. 728A	Häggsjöliden	ca. 66°00'	3.5 — 1.6	Burgtorf (1981)
4. D98	Moskosel	65°52'	2.8	Möller (1982) pers.comm.
5.	Norrliden	ca. 64°10'	2.9	Albrektson et al. (1977)
6. D157	Bomsund	63°05'	6.4	Möller (1982) pers.comm.
7. 731	Lövnäs	ca. 61°30'	5.8 — 2.3	Burgtorf (1981)
8. 731A	Bleckstugan	"	5.9 — 2.3	" "
9.	Åheden	ca. 61°00'	3.4	Albrektson et al. (1977)
10.	Ivantjernsheden	ca. 60°40'	—	Aronson (1982) pers.comm.
11.	Lisselbo	ca. 60°30'	1.9	Albrektson et al. (1977)
1.—11. Range		66°30' — 60°30'	5.9—1.6	
Mean			3.4	

Table 1 presents data on peatland research sites in Norway where boron deficiency is proved by combining diagnostic methods like: characteristic growth disorders, needle analyses, response tests to boron fertilizers. Boron contents in last year needles of Norway spruce on the sites which were tested, varied from 1.4 to 4.7 ppm B with average at 2.5 ppm. The range for Scots pine needles was from 1.0 to 9.9 ppm B with 4.9 ppm B as mean. This reflects the general impression that on boron poor peatland sites Scots pine usually has higher boron contents in last year-needles than Norway spruce.

In Table 2 boron deficiency sites in

Sweden are listed. These are Scots pine stands on fertilized mineral soils. All stands have typical "shoot die-back" and low boron contents in last year-needles, however, boron fertilizer response test is only done for a couple of the sites. Boron contents in last year-needles for the eleven sites (Table 2) range from 1.6 to 5.9 ppm B with mean at 3.4 ppm.

The locations of the sites listed in Tables 1 and 2 are plotted on Fig. 1. The geographical distribution is typically inland oriented.

A hypothesis which can help in pinpointing susceptible areas for induced boron deficiency, may be based on the following assumptions:

a. Marine limit forms a threshold for boron contents in soil. Salt water sediments are richer on boron than fresh water sediments and moraine soils above marine limit (Landergren, 1945).
b. Distance to sea on prevailing wind direction is important for atmospheric deposition rate. Sea water contains about 4.7 mg B/l. The atmospheric fall out of boron rich particulates will be most intensive at the coast and decrease inland like clorine.
c. Some soil types will be more boron poor than others. Generally soils derived from ultrabasic or basic igneous rocks, limestones and gneisses have lower boron contents than soils from other parent rock materials (Wells and Whitten 1977). Within the mentioned groups outwashed sandy soils low in organic matter, waterlogged soils, nutrient poor deep peat soils could be susceptible.

On Figure 1 susceptible regions are traced out by assumptions a and b. The line is put about 20 km inland from main coastline along the Baltic Sea and North Sea, and 60 km inland along the North Atlantic. Areas below marine limit inside the line is shaded. In Götaland the inland plateau above marine limit is traced out with no correction for distance to sea. Nearly all described sites with boron deficiencies are located inside the line and above marine limit. This gives reason to accept the mentioned hypothesis for further tests. The soil types mentioned under point c, should be the most susceptible ones inside the line. Ivantjernsheden and Lisselbo NW of Uppsala lies outside the proposed line. These sites show that boron deficiency can also be induced below the marin limit after manipulations of the nutrient cycles on sandy soils with nitrogen fertilizer and liming.

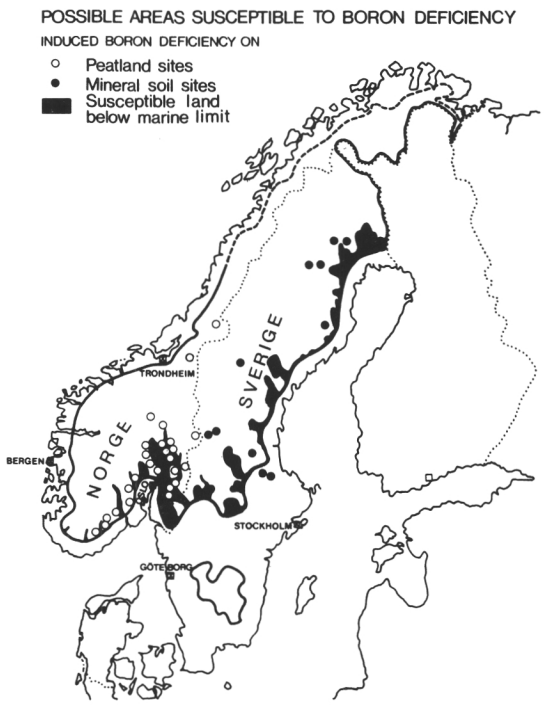


Figure 1. Location of boron deficient stands listed in Tables 1 and 2. Inland areas which are supposed to be susceptible to induced boron deficiency, are indicated by the full drawn line.

Until more specific studies on boron uptake for the mentioned soil types in the inland province of Götaland has proved or disproved susceptibility, we must support the hypothesis that boron deficiencies in forest trees might occur in that region as well.

The geographical distribution of boron contents in water drained from Sweden and Norway reflects integration of factors like: population density, development of agriculture, atmospheric deposition of boron and mineral acids, geological characteristics etc. (Ahl and Jönsson 1972). Therefore Figure 2 should be used carefully for the purpose of selecting regions with boron poor soils. Despite this Figure 2 indicates that areas above marine limit north of latitude 60° N has low boron contents in the outflowing water both in Norway and Sweden ($B < 8$ μg/l). Except for coastal areas at the North Sea and the Atlantic, Figure 2 is in good agreement to the large inland province traced on Figure 1. Boron contents in

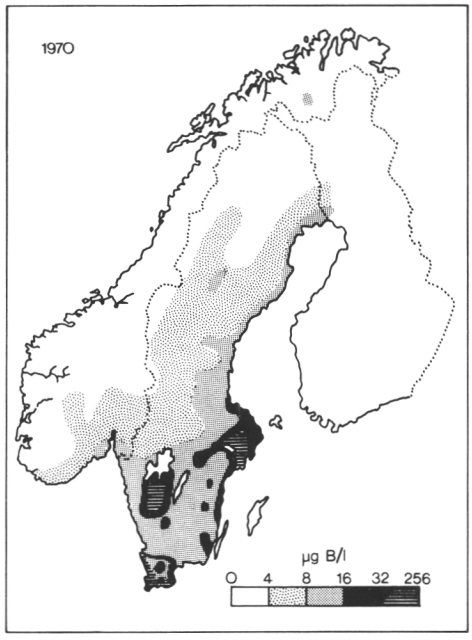


Figure 2. Regional pattern of boron in Scandinavian fresh water 1970. (Modified from Ahl and Jönsson 1972).

output water from catchment inside this province should therefore be a useful indicator on ecosystem susceptibility to boron deficiencies although local deviations are likely to exist.

Conclusions

Micronutrient deficiencies are seldomly reported for natural boreal forests. Drainage, fertilization, whole tree harvesting technics, air pollution etc. can alter nutrient cycling processes in such stands so that imbalanced nutrient uptake is induced.

It is by now clear that N-fertilizations on mineral soils and PK- and NPK-fertilizations on deep peat can induce boron deficiency on inland sites. Heavy drought in the growing season may also reduce availability and/or uptake of boron so that deficiencies develop. The most susceptible stands are such with shallow rooting and a general low boron uptake.

Boron deficiencies on mineral soils should primarily be expected above marine limit in Norway and Sweden. Volcanic and granitic parent soil materials, highly weathered soils, sandy soils low in organic matter, and waterlogged soils are possible boron poor soil types where stands could be susceptible to induced boron deficiency (Snowdon, 1971; Lambert, 1981).

On deep nutrient-poor peat in Norway, drainage and fertilization have induced boron deficiency at certain distances from coastline. This is about 20 km in southeast and 60 km on the westcoast. It is reason to expect similar critical distances in Sweden. This means that nutrient-poor deep peat in a large inland province of Fennoscandia is susceptible to boron deficiency after afforestation.

So far there has been no reports on large scale deficiencies on any other micronutrient in Fennoscandian forests.

Literature

AHL, T. & JÖNSSON, E. 1972. Boron in Swedish and Norwegian Fresh Waters. Ambio 1(2):66—70.

ALBREKTSON, A., ARONSON, A. & TAMM, C.O. 1977. The effect of forest fertilization on primary production and nutrient cycling in the forest ecosystem. Silva Fennica 11:233—239.

ARONSSON, A. 1980. Frost hardiness in Scots pine (*Pinus sylvestris* L.). II. Hardiness during winter and spring in young trees of dirrerent mineral nutrient status. Stud. For. Suec. 155:1—27.

— ELOWSON, S. & FORSBERG, N.-G. 1978. Torkskador på gran i Västmanland. (Drought Damage on Spruce in Southern Sweden.). Sv. Skogsvårdsforb. Tidskr. 76:441—456.

BARKLUND, P., BEYER-ERICSON, L., HYPPEL, A., JOHANSON, M., LINDEBERG, G & WÄSTERLUND, I. 1977. "Sub top dying" — en skade på gran av "die-back"-typ. Skogen 64:606—608.

BRÆKKE, F. H. 1977. Fertilization for balanced mineral nutrition of forests on nutrient-poor peatland. Suo 28(3): 53—61.

— 1979. Boron deficiency in forest plantations on peatland in Norway. Medd. Nor. inst. skogforsk. *35*:213—236.

— 1980. Boron deficiency on afforested peatlands in Norway. Proc. 6th Int. Peat Congress, Duluth, Minnesota, U.S.A. Aug. 17—23, 1980. 735 pp.

— 1982. Micronutrients — prophylactic use and cure of forest growth disturbances. (Presented elsewhere in this publication.)

BURGTORF, H. 1981. Effekten av växtnäringstillförsel till några tallbestånd på näringsfattig mark i kyliga klimatlägen. (The effects of supply of plant nutrients to some pine stands on poor and cold sites.) Rapp. skogsekol. skogl. marklära *37*:1—34.

LAMBERT, M. 1981. Physiology and management of micronutrients in forest trees in Australia. Aust. tree nutr. Works., Canberra, 10—14 August 1981.
LANDERGREN, S. 1945. Contribution to the geochemistry of boron. II. The distribution of boron in some Swedish sediments, rocks, and iron ores. The boron cycle in the upper lithosphere. Arkiv för Kemi, Mineralogi och Geologi *19A* (26):1—31.
MESHECHOK, B. 1968. Om startgjødsling ved skogkultur på myr. (Initial fertilization when afforesting open swamps.) Meddr. norske Skogsfors-Ves. *25*(1):1—140.
SNOWDON, P. 1972. Observation on boron deficiency in *Pinus radiata*. In: Boardman, R. (Ed.). Aust. Forest-Tree Conf. Sept. 1971. Canberra, A.C.T. Forestry and Timber Bureau., p. 191—207.
WELLS, N. & WHITTON, J. S. 1977. A pedochemical survey. 3. Boron. New Zealand J. Sci. 20:317—332.
Total of 15 references

DISTURBANCES IN THE SEASONAL GROWTH OF SCOTS PINE DUE TO WATER-LOGGING OF THE ROOTS

Stanislav E. Vompersky

The paper presents the results of long-term investigations of the seasonal growth of Scots pine stands growing on peat soil characterized by different degrees of drainage and fertility. It has been established that the typical dynamics of growth during the growing season, as well as the duration of growth in years with a favourable amount of precipitation, are altered in rainy years. This results in the prolongation of the growth period and later onset of the maximum seasonal growth rates. In the year following a rainy one, the growth period is, on the contrary, reduced. The daily growth increments, specifically those for tree diameter in the latter half of the growing season, decrease, the synchronisation in the dynamics of increment both in heigh and in diameter is disturbed and the overall seasonal increment is reduced.

Disturbances in the normal seasonal growth pattern of pine during rainy years have been studied within the framework of a more general programme of investigations in peatland forest ecology (Vompersky 1968, 1973). Similar ecological programmes have been carried out in the USSR (Zalitis 1963, Orlov and Koshelkov 1971, Smolyak and Reutsky 1971) and in other countries, primarily in Finland and Sweden (Huikari and Paarlahti 1967, Leikola and Paavilainen 1972, Holmen 1964).

The present paper presents the general results of investigations into the seasonal growth pattern of Scots pine stands in years with normal (average) weather conditions, and rainy years when all the forests growing on peatland soils, including the drained ones, are negatively affected by water-logging of the root systems.

The investigations were carried out in 20 to 40-year-old Scots pine stands growing on peatland sites with different drainage intensities. In every variant of forest drainage intensity, the growth increments of the shoots of 20 trees were measured every 5—10 days and increment cores of the stem-wood were taken at a height of 1.3 m in order to make anatomical studies on the annual rings. Measurements of the air and soil temperatures and the depth of the groundwater table were also made. All these observations were conducted in the Leningrad area over a period of 7 years.

In our conditions, tree stands begin to grow at the end of April / first half of May with little dependence on the degree of soil drainage. The air temperature, however, is of decisive significance. At this time of the year the soil is either frozen or flooded, but

this has no effect on the onset of shoot growth. Despite the conditions in the soil, the growth rates in spring are by far higher than those at the end of the growing season. On the average, the first 5 % of annual increment in height and diameter are formed at a velocity rate which is 3—6 times faster than that at the end of the growing season, when the hydrothermal regime in most cases is more favourable. This is in agreement with the concept that tree growth at the beginning of the growing season is predominantly a result of the use of carbohydrates accumulated during the preceding year. The growth rates in the middle of the growing season and during its second half are significantly dependent on the abiotic factors. They are also conditioned by the physiological status of the growing organs, availability of nucleoproteins and phytohormones in cambial tissues. All this restricts the possibility of establishing direct correlations between the external conditions and the daily increments of trees.

Figure 1 presents a typical pattern of annual increment in height and diameter during an average year, in terms of humidity, in stands of different productivity and degree of soil drainage. In a well-drained peat soil, the groundwater table during the growing season was on the average at a depth of 48 cm, whereas in the least intensively drained one it was at a depth of 23 cm.

The dynamics of height growth increment are similar in stands with a different water regime and productivity. The same is characteristic of the increment in diameter during the first half of the growing season. Significant differences appear in July—August when the 2nd peak in diameter increment is observed under highly productive conditions. This increment is associated with the formation of thick-walled tracheids, which improve the structure of the annual ring. Under favourable weather conditions, the second peak in diameter growth in well-drained forests can reach the rates of the first peak with a rate of growth of the annual layer of 1—2 rows of tracheids per day. On non-drained swamps, pine at this time of year forms only one row of tracheids every 4—8 days.

Significant deviations from the typical seasonal growth are observed in rainy years

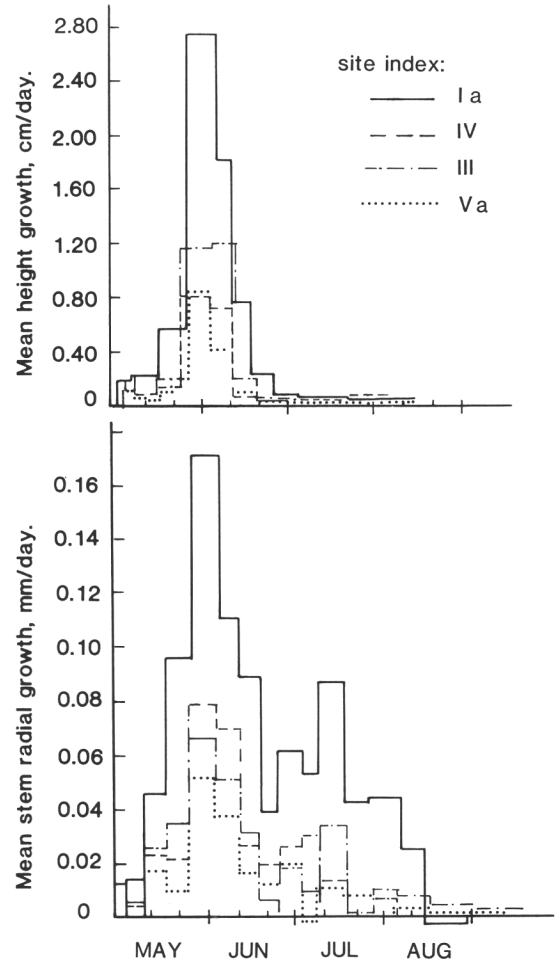


Figure 1. The typical seasonal growth of Scots pine in years with favourable level of precipitation.

and, especially, in the years that follow them (Fig. 2). The total period of growth in height lengthened by 20—40 % and the maximum increment, being delayed by 2—3 weeks, fails to reach the level of the preceding years.

The strongest changes in the seasonal growth dynamics are observed in the year following the rainy one:

— synchronisation of seasonal growth in different stands as well as the synchronisation of different kinds of increment within one stand are disturbed;
— the second peak in diameter increment in poorly drained pine forests is not observed;
— the total period of stand growth is reduced and decreased daily maximum increment is observed 1—2 weeks earlier than usual;
— the overall annual increment is reduced.

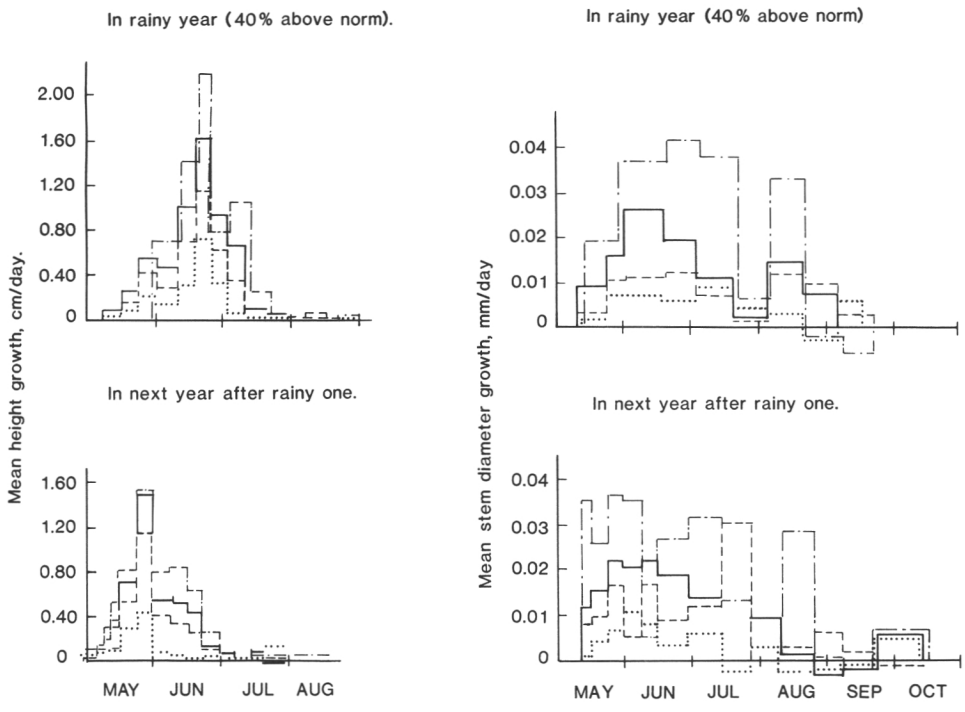


Figure 2. Seasonal growth of pine (site index, see Fig. 1).

Disturbances in the characteristic growth dynamics during the first rainy year can be explained by the discrepancy between good initial physiological status of the cambial tissues and the predominance of anaerobic conditions in the soil which are responsible for the atrophy of the roots. This results in the disturbance of metabolism and the "normal" dynamics of seasonal growth. Moreover, during a rainy year trees fail to create a sufficient reserve of physiologically active substances needed for successful growth in the future. Therefore during the next (after a rainy year) growing season the increment decreases even in efficiently drained forests, whereas in the poorly drained ones a considerable part of the carbohydrates must be consumed in the regeneration of the dead roots at the expense of the increment of the above-ground parts.

The annual increment level in stands growing on well-drained soils is regained 1—2 years after a rainy season, whereas on inefficiently drained soils they are not restored until after 3—4 years. The correlation between the mass of active roots and the assimilation apparatus is also restored by that time.

The following statements should be made in conclusion:

— the possibility of completely preventing disturbances in the growth of trees on peat soils duet to water-logging of their roots is rather problematic. However, the degree of soil drainage must be such that it ensures normal growth of the trees not only during average years, with respect to the amount of precipitation, but also during frequently occurring rainy years;
— while making a dendrochronological analysis of the growth of trees on swamps, one should take into account that increment is decreased not during the rainy year but during the following 1—2 years.

Literature

HOLMEN, H. 1964. Forest ecological studies on drained peatland in the province of Uppland, Sweden. Parts I—III. Stockholm, 236 p.

HUIKARI, O. & PAARLAHTI, K. 1967. Results of field experiments on the ecology of pine, spruce and birch. Commun. Inst. For. Fenn. 64(1): 1—121.

LEIKOLA, M & PAAVILAINEN, E. 1972. Water uptake of pines from frozen soil. In: Isotopes and radiation in soil plant relationships including forestry. Vienna.

ORLOV, A. YA. & KOSHELKOV, S. P. 1971. Pochvennaya ekologiya sosny. "Nauka", Moskva, 323 p.

SMOLYAK, L. N. & REUTSKY, V. G. 1971. Ekologo-fiziologitcheskie osnovy melioratsii lesnykh potchv. "Nauka i tekhnika". Minsk, 157 p.

VOMPERSKY, S. E. 1968. Biologicheskie osnovy effektivnosti lesoosucheniya. "Nauka", Moskva, 312 s.

— 1973. Biologisheskie osnovy lesoosucheniya. V.Kn.: "Voprosy kompleksnogo izutcheniya bolot." Petrozavodsk, pp. 141—152.

ZALITIS, P. P. 1963. Dinamika sezonnogo prirosta elovykh molodnjakov zavisimosti ot stepeni osusheniya. V.Kn.: "Povyshenie produktivnosti lesa". Izd-vo AN Latv.CCR, Riga, pp. 51—57.

Total of 8 references

GROWTH DISTURBANCE OF CARIBBEAN PINE IN THE TROPICAL RAIN FOREST REGION

Wawan Kustiaman, Ichiro Hongo and Hirozumi Kataoka

Introduction

Foxtailing appears to be one growth disturbance pattern which is found in low latitude pine plantations, especially in caribbean pine (*Pinus caribaea* var. *hondurensis*) and merkusii pine (*Pinus merkusii*) stands.

Foxtailing is an undesirable characteristic of pine species. As a result of foxtailing, the pine tree is easily broken by wind blow and sometimes compression wood is formed in the stem.

There are many arguments about the cause of foxtailing, it being attributed to environmental factors and genetic inheritance.

For instance, Kozlowski and Greathouse (1970) pointed out that the occurrence of foxtailing is markedly affected by climatic factors such as temperature and precipitation on the site. Ibrahim and Greathouse (1972) reported that the occurrence of foxtailing was higher on poor soil and Luckoff (1964) pointed symptom also. However, Hamazah and Natawiria (1974) suggested that foxtailing was more common on rich soil. On the other hand, Chiba (1979) supported the genetical point of view.

In this paper, some results concerning the occurrence of foxtailing in the case of caribbean pine based on environmental study at the Balikpapan district in East Kalimantan Indonesia are briefly described.

Characteristics of study area

The study area, which was chosen from young caribbean pine plantations of International Timber Corporation, Indonesia (I.T.C.I.), is situated between 116°30'—117°30' east longitude and 0°15'—1°10' south latitude approximately. This study area is topographically a flat to gentle slope and elevation of less than 50 m above sea level. The soil type of the stand belongs to the reddish yellow podzolic soil derived from old igneous and sedimentary rocks. The climate of the study area belongs to the lowland rain forest tropics. The annual mean rainfall is 3050 mm and monthly mean temperature is 27°C. Usually, short dry season occurs once a year, except in wet year.

Method

A five-year old caribbean pine stand mixed with foxtailing and normal trees was selected. In March 1982, the top shoot needles were collected individually from five trees each for needle analysis. Surface soil, 0—10 cm in depth and subsurface soil, 30—40 cm in depth of five trees of each were collected for soil analysis. The needle analysis and soil analysis were taken on a C.H.N. analyzer and an X-ray fluorescence spectrometer.

Results and discussion

Foxtailing type

There are many foxtailing types in the selected site and it can be divided into four types fundamentally as follow. These types are just same as the four types that Kozlowski and Greathouse (1970) have recognized in a Malaysian caribbean pine plantation.

Type-A. Single shoot elongated continually after planting on the field, therefore producing a stem without branches.
Type-B. Formation of foxtail starts some years after planting but then stops several years later, after which it grows back to normal.
Type-C. At the beginning, the tree grows normally and then the foxtail appears later continually.
Type-D. Foxtail had appeared after the tree had been planted on the field but it stopped for certain time and the foxtail appears again.
Type-C. was most common on the site and Type-A was the rarest.

Growth of normal and Type-C foxtailing tree

The mean height and diameter at breast height of normal trees and Type-C foxtailing trees are presented in the following:

Foxtail	Growth by tree type		
	High (m)	D.B.H. (cm)	H/D
Normal	7	9	77.8
Foxtail	9	8	112.5

There are differences in growth between normal and foxtailing trees and the ratio of height — diameter at breast height indicate that Type-C foxtailing tree is easy broken by wind blow and easily bends.

Chemical properties

Total amount of each nutrient in the surface soil, subsurface soil and needles are shown in Tables 1—3 (p. 30).

It can be seen from the presented results, that the soils rich in organic matter, N and P affected the occurrence of foxtailing. The movement of litter from the upper layer plays an important role in soil fertility. As the soil becomes poor, or as a result or run off in the litter and the soil becomes rich by accumulation of litter especially in tropical rain forest region.

In conclusion, it seems that the genetical considerations are never negligible in order to avoid the occurrence of foxtailing but the environmental considerations which relate to the tree physiology are also indispensable.

Acknowledgements

We would like to thank Mr. Sambas WIRAKUSUMAH the former rector of Murawarman University for suggesting this problem and for stimulating interest in it. We are grateful to prof. Dr. Soetrisno HADI the rector, Dr. RIYANTO, staff members Forestry Department of Murawarman University and prof. Syafii Manan of Bogor Agricultural University for their hearfert assistances.

Literature

CHIBA, S. 1979. Observations on the growth and characteristics of caribbean pine at the test plantations established in Malaysia. Tropical Agriculture Research Series 12: 11—23.

HAMAZAH, Z. & NATAWIRIA, D. 1974. Foxtail on *Pinus merkusii* Jungh. et de Vr. Depertemen pertanian direktorat jenderal kehutanan Lembaga Penelitan Hutan, Laporan 181: 1—15.

IBRAHIM, S. & GREATHOUSE, T. E. 1972. Foxtailing in exotic pines. Premilinary results of a study in West Malaysia. Malay Forester 35(1): 17—23.

KOZLOWSKI, T. T. & GREATHOUSE, T. E. 1970. Shoot growth and from in pines in the tropics. Unasylva 24(4).

LUCKOFF, H. A. 1964. The natural distribution, growth and botanical variation of *Pinus Caribaea* Mor. and its cultivation South Africa. Ann. Univ. Stellenbosh 39: 1—160.

Total of 5 references.

Table 1. Chemical properties of the surface (0—10 cm in depth) soil by tree type

	C (%)	N (%)	MG (%)	Al (%)	Si (%)	P (%)	K (%)	Ca (%)	Fe (%)	Co $\mu g \cdot g^{-1}$	Ni $\mu g \cdot g^{-1}$	Cu $\mu g \cdot g^{-1}$	Zn $\mu g \cdot g^{-1}$	Sr $\mu g \cdot g^{-1}$
N	1.40	0.19	0.41	8.27	39.76	0.02	1.26	0.03	5.11	13.4	38.4	72.8	44.5	59.0
F	2.29	0.25	0.41	8.38	40.50	0.06	1.26	0.03	5.59	16.6	39.7	71.7	50.0	41.0
F/N	1.64★	1.32★	1.00	1.01	1.20	3.00★★	1.00	1.00	1.09	1.2	1.0	1.0	1.1	0.7

Table 2. Chemical properties of the subsurface (30—40 cm in depth) soil by tree type

N	0.65	0.16	0.36	11.60	37.16	0.02	1.13	0.02	5.17	19.7	36.8	76.9	53.5	76.7
F	1.02	0.16	0.36	10.20	35.91	0.03	1.02	0.02	5.10	18.8	36.3	76.3	55.1	68.3
F/N	1.57★	1.00	0.94	0.88	0.97	1.50★	0.90	1.00	0.99	1.0	1.0	1.0	1.0	0.9

Table 3. Chemical properties of the top shoot needle by tree type

	C (%)	N (%)	MG (%)	Al (%)	Si (%)	P (%)	K (%)	Ca (%)	Fe (%)	Co $\mu g \cdot g^{-1}$	Ni $\mu g \cdot g^{-1}$	Cu $\mu g \cdot g^{-1}$	Zn $\mu g \cdot g^{-1}$	Sr $\mu g \cdot g^{-1}$
N	44.87	1.13	0.12	0.07	—	0.06	1.17	0.31	0.01	1.6	4.0	3.0	60.4	3.4
F	44.47	1.24	0.19	0.06	—	0.08	1.15	0.41	0.01	1.5	4.5	3.5	61.0	3.3
F/N	0.99	1.10	1.58★	0.86	—	1.33★	0.98	1.32★	1.00	0.9	1.1	1.2	1.0	0.9

(★ : statistically significant, ★★ : very significant)

N = normal tree
F = type-C foxtailing tree

SESSION 2.

DIAGNOSTICAL METHODS IN GROWTH DISTURBANCE RESEARCH

DEVELOPMENT OF GROWTH DISTURBANCE IN SCOTS PINE

Klaus Silfverberg

The development of growth disorder was studied in a heavily fertilized 12-year-old Scots pine plantation on peat. The study was carried out at Kivisuo (61°51'N, 25°59'E) during 1977 and 1978. The trees selected for monitoring were healthy-looking and amounted to 153. Visible die-back occrurred in early summer during the shoot growth period. Dryness and soil frost might have increased the die-back frequency. Prediction of die-back seemed difficult, because there were no clear preceding symptoms. Damage thus appeared suddenly and was rather extensive. An inventory in 1982 revealed that about 50 % of the trees studied were dead, partly due to secondary agents. Dense planting space increased the mortality of damaged trees.

In the early stage of growth disturbance research in Finland there was a need for identifying the micronutritional growth disturbances among several other disturbances. There was also a need for prediction the occurrence of the disturbance. The timing, development and impacts of micronutritional dieback were also of interest. A minor study concerning these problems was carried out at Kivisuo (61°51'N, 25°59'E) during 1977 and 1978.

Kivisuo was originally a cotton-grass bog, drained in 1945—47 using 22 m draining space and then used as a drying field for fuel peat. In 1953 these activities ceased and Kivisuo was made an experimental field for

peatland afforestation and fertilization (Huikari and Paarlahti 1973). The area studied was located in experiment XIII. This experiment was established in 1966 by planting Scots pine, 2+1 yrs, in rows parallel to the ditch margins. Simultaneously the plots received heavy NPK-fertilization (1000, 2000 or 4000 kg/ha; N 14, P 8, K 8 %) on a 1 m broad strip. In 1974 PK-refertilization was carried out, also as strip (2000 kg/ha; P 9, K 17 %). The planting spaces were 1.5, 1.0 and 0.5 in the row. Correspondingly the number of seedlings were 2400, 3550 and 7100/ha. Because the study material was from 6 plots (455, 456, 462, 463, 464, 465) variations in basic fertilization and planting space occurred.

Chiefly due to the low boron contents in the needles (see below, cf. Kolari 1979, Braekke 1977) this field was considered as a potential die-back area suitable for monitoring.

	N	P	K	Ca	Mg	Cu	Mn	Zn	B
			%				ppm		
Healthy-looking, 1976	1,55	0,19	0,54	0,22	0,14	4,8	192	54,3	3,8
Die-back trees, 1976	1,79	0,24	0,68	0,22	0,13	5,1	149	59,0	3,4
Healthy-looking, 1982	1,69	0,20	0,58	0,31	0,10	4,8	277	54,0	5,4

Prior to the study there had been occasional die-backs in the area. 153 healthy-looking pines were chosen for the study to observe growth and general morphological development.

These healthy-looking trees were deliberately chosen from the vicinity of small die-back patches where outbreak of disturbance seemed probable. Measurements included the total height, the height growth of 1973—78 and mean breast height in autumn 1977. The mean of the total height was 297 cm and that of the $d_{1,3}$ was 4,3 cm, when the trees were chosen.

According to Veijalainen's unpublished inventory from September 1976 in plots 455, 456 the means of the total heights were 309 and 277 cm, and those of $d_{1,3}$ were 3,7 cm and 3,3 cm, respectively. In this material the means of the total height were 294 and 271 cm, those of the breast heights were 3,7 and 3,2 cm. The selected trees were thus rather representative, at least for these two plots. The morphological development and growth of the shoots were monitored 4 times during 1977 and 7 times during 1978. A final inventory was carried out in October 1982.

In the plots studied, though not in study trees, there were frequent pre-symptoms originating since planting. The most typical early symptom was weakened apical dominance, which appeared as vertical branches and forking of shoots. Some other pre-symptoms, considered to be typical of growth disturbance, also occur in connection with fertilization, southern provenance and wide spacing. Among these were excessive needlemass, branchiness and a stunted appearance (Reinikainen 1967, Veijalainen 1975, Kurkela 1981).

Visible die-back generally occurred during the height-growth in May-June. Probably due to anatomical injuries the apical buds developed no or, mostly, uncomplete shoots (Braekke 1977, Raitio & Rantala 1977, Raitio 1979). In most cases these defective shoots died within one year. Repeated die-back then often led gradually to a bushy tree (Figs. 1, 2). This happening in originally symptomless trees shows that die-back may occur without preceding, early or late, symptoms. Most of the symptoms usually seen on disturbance areas (needle-cast, -deformations and -colour; deformation of shoots) are results of the acute and chronic stage of the disturbance or secondary damage (Veijalainen 1975).

In October 1982 the trees were classified in healthy-looking, injured and dead. The size of the tree in spring 1977 seems to have had an influence on die-back frequency (see below).

	Healthy-looking	Injured	Dead
Height, cm	322 ± 20	302 ± 14	283 ± 13
$D_{1,3}$ cm	5,2 ± 0,5	4,8 ± 0,4	4,7 ± 1,1

Affected trees had originally been slightly smaller than non-affected. Thus we can suppose that the small trees in a stand might be more sensitive to die-back and secondary agents connected to it than the bigger ones. Height growth preceding die-back 1977 revealed only few and relatively small deviations from non-affected and control



Figure 1. Secondary shoot after die-back in leader 21.6.1978.



Figure 2. Repeated die-back leads to a bushy appearance. Photo: K. K. Kolari.

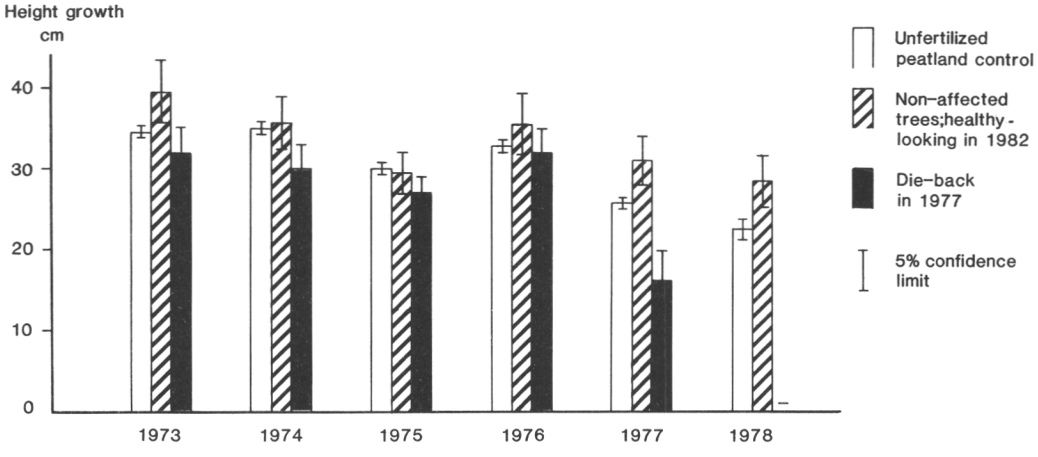


Figure 3. Height growth preceding die-back. Year of die-back = last year with growth on leader.

trees (Fig. 3). The appearance of die-back was thus rather sudden even in this respect.

The annual number of die-backs were compared with corresponding early summer precipitation in the older experiment I nearby (Fig. 4). There seemed to be a relationship between low precipitation and die-back frequency. Kivisuo I was refertilized in 1968 (NPK 500 kg/ha) but the peak was similar in the non-refertilized plots. Die-back reached its maximum 11 years after planting in the same way as later

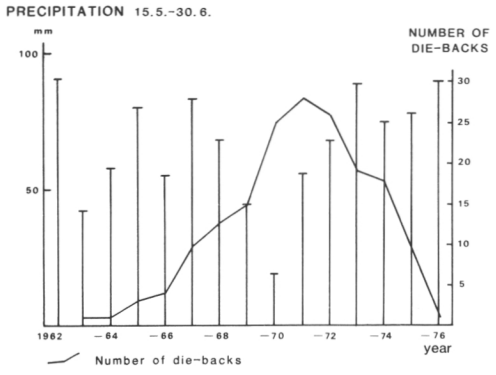


Figure 4. Annual die-back frequency compared with early summer precipitation. Kivisuo I. (Kosonen & Silfverberg 1976)

in experiment XIII. The die-back peak may thus as well be a consequence of developmental stage (cf. also Kunelius 1982).

Strip-fertilization and -planting parallel to the ditch-margins may also cause some problems. If strip-fertilization restricts the roots to the NPK-fertilized area (cf. Hauge 1971), the uptake area of other nutrients is reduced without compensating fertilization. Frozen and effectively drained peat is known to melt late in spring (Pessi 1958, Heikurainen 1980). Braekke (1977) has reported that soil frost induced die-back in Norway and in Finland (Kunelius 1982) has got similar results. In 1978 peat in some places was found to be still frozen in June at experiment XIII and may even have caused some die-back there.

Prediction of growth disturbance seems to be difficult, mainly because of the variation in abiotic factors e.g. climatic conditions. In single trees the symptoms were mostly absent or coincided with the die-back. Therefore symptoms should be used to prejudge the disturbance risk for total stands rather than for single trees. Due to the initial symptomlessness and the short monitoring time the prejudgement value of symptoms remains, however, somewhat unclear.

The simplest way of prediction has proved to be observations of die-back frequency combined with foliar analysis. These can be used indicating disturbance probability for the whole stand. It should be pointed out that even a low frequency of disturbance often gives reason for curing methods. In the present material about 50 % of the trees, originally classified as healthy-looking, were affected in 1977 and 1978 (Silfverberg 1979), and in October 1982 50 % were dead (cf. Veijalainen 1982). Some die-back trees of 1977 were classified healthy-looking in 1982. This shows that external recovery can take place after die-back. Only 21 % of the trees being healthy-looking in 1982 indicates, however, also a continuation of the die-backs (Table 1). Damage was thus sudden, rapid and extensive. The importance of preventive action is obvious. Special attention should be paid when fertilizing or refertilizing with NPK (Veijalainen 1977, Paavilainen 1979). Drainage effect, growth of stand, foliar nutrient status, earlier fertilization and site characteristics also be considered.

The impacts on the stand were of different intensity. Slightly affected trees, e.g. recovered from one die-back, suffered from growth and quality losses, while in severe cases trees died, often due to secondary agents. The formation of uneven stands is harmful in the long run. Suppressed trees often succumb due to poor light conditions, fungal diseases etc. This seems to be especially true when using dense planting space (Table 1). Separation between primary and secondary damage as well as normal competition can be difficult at that stage.

This report should for several reasons be understood as a singular case. The very scarce material and study time along with extremely heavy fertilization and the special background of Kivisuo makes generalizations of these results doubtful.

Table 1. Effect of basic fertilization and planting space on study trees. Inventory in October 1982.

	Basic fertilization, NPK kg/ha					
	1000			2000		
Planting space, m	1,0	0,5	1,5	1,0	0,5	$\bar{x}$
n =	26	33	24	12	46	
Healthy-looking, %	38,4	9,1	16,6	20,0	21,7	20,8
Injured, %	46,2	6,1	54,2	20,0	21,7	28,0
Dead, %	15,4	84,8	29,2	60,0	56,6	51,2

Literature

BRAEKKE, F.H. 1977. Fertilization for balanced mineral nutrition of forests on nutrient-poor peatland. Seloste: Turvemaiden tasapainoinen lannoitus. Suo 28(3):53—61.

HAUGE, T. 1977. Rotutvikling etter planting og gjødsling av gran på myr. Resultater etter 6 vekstsesonger. Summary: Root development after plantig and fertilization of Norway spruce on bog. Results after 6 growing seasons. Tidsskrift for Skogsbruk 3:315—326.

HEIKURAINEN, L. 1980. Metsäojituksen alkeet. II painos. Helsinki. 284 s.

HUIKARI, O. & PAARLAHTI, K. 1973. Kivisuon metsänlannoituskokeet. Kenttäopas, 2. painos. Helsinki 57 s.

KOLARI, K.K. 1979. Hivenravinteiden puute metsäpuilla ja männyn kasvuhäiriöilmiö Suomessa. Kirjallisuuskatsaus. Abstract: Micronutrient deficiency in forest trees and die-back of Scots pine in Finland. A review. Folia For. 389:1—37.

KOSONEN, R. & SILFVERBERG, K. 1976. Havaintoja eskimosis-ilmiöstä männyllä Kivisuolla 1976. Metsäntutkimuslaitoksen suontutkimusosaston tiedonantoja 8. 15 s.

KUNELIUS, K. 1982. Männyn kasvuhäiriöt metsitetyllä suopellolla ja ojitetulla rämeellä. Metsänhoitotieteen laudaturtyö yleistä metsätutkintoa varten. 68 s.

KURKELA, T. 1981. Versosyöpä *(Gremmeniella abietina)* riukuasteen männiköissä. Summary: Canker and die-back of Scots pine at precommercial stage caused by *Gremmeniella abietina.* Folia For. 485:1—12.

PAAVILAINEN, E. 1979. Metsänlannoitusopas. Kirjayhtymä. 112 s. Helsinki.

PESSI, Y. 1958. On the influence of bog draining upon thermal conditions in the soil and in the air near the ground. Acta Agriculturae Scandinavia vol. VIII:4, 359—374.

RAITIO, H. 1979. Boorin puutteesta aiheutuva männyn kasvuhäiriö metsitetyllä suopellolla. Oireiden kuvaus ja tulkinta. Abstract: Growth disturbances of abandoned peatland field. Description and interpretation of symptoms. Folia For. 412:1—16.

— & RANTALA, E-M. 1977. Männyn kasvuhäiriön makro- ja mikroskooppisia oireita. Oireiden kuvaus ja tulkinta. Summary: Macroscopic and microscopic symptoms of a growth disturbance in Scots pine. Description and interpretation. Commun. Inst. For. Fenn. 91(1):1—32.

REINIKAINEN, A. 1967. The appearance of nutrient deficiency in plants growing in the experimental area for forest fertilization at Kivisuo. Proc. of the 5th Colloquim of the Int. Potash Inst. 345—361.

SILFVERBERG, K. 1979. Männyn kasvuhäiriön ajoittuminen ja alkukehitys turvemaan boorinpuutosalueella. Abstract: Phenology and initial development of a growth disorder in Scots pine on boron deficient peatland. Folia For. 396:1—19.

VEIJALAINEN, H. 1975. Kasvuhäiriöistä ja niiden syistä metsäojitusalueella. Summary: Dieback and fertilization on drained peatlands. Suo 26(5):87—92.

— 1977. Use of needle analysis for diagnosing micronutrient deficiencies of Scots pine on drained peatlands. Seloste: Neulasanalyysi männyn mikroravinnetilanteen määrityksessä turvemailla. Commun. Inst. For. Fenn. 92(4):1—32.

— 1982. Micronutrient mixture experiment in an intensively fertilized Scots pine stand. Excursion quide. International Workshop on Growth Disturbances of Forest Trees. Leivonmäki-Kivisuo 13.10. 1982, pp. 12—14.

Total of 17 references

MACRO- AND MICROSCOPICC SYMPTOMS IN GROWTH DISTURBED FOREST TREES

Hannu Raitio

With the intensification of afforestation and fertilization activities in the last few years, also growth disturbances have been encountered especially in the afforestation areas of drained peatlands and former peatland fields and in nurseries. Growth disturbances are characterized by the death of apexes and leaders and by various irregularities in the apical dominance. Repeatedly damaged trees gradually become bushy. The stem is thick and short with plenty of branch and needle mass in relation to stemwood. Affected needles are thick (disproportionately thick in relation to their length), dark green, spiral or sickle shaped.

Typical microscopic symptoms are browning of cells, overgrowth of the cells, cavities, thin secondary wall of schlerenchyma and deformation of vascular bundles.

Introduction

With the intensification of afforestation and fertilization activities in the last few years, also growth disturbances have been encountered especially in the afforestation areas of drained peatlands and former peatland fields and in nurseries. Growth disturbances in pine are characterized by the death of apexes and leaders and by various irregularities in the apical dominance. Repeatedly damaged trees gradually become bushy (Raitio and Rantala 1977). The stem is thick and short with plenty of branch and needle mass in relation to stemwood (Reinikainen and Silfverberg 1983). Numerous investigations suggest that a micronutrient shortage is the chief cause (Huikari 1974, Veijalainen 1975, 1977, Raitio and Rantala 1977, Kolari et al. 1977, Raitio 1979, 1981).

The nutrient deficiency symptoms in conifers have been mainly described by morphological symptoms (Goslin 1959, Baule and Fricker 1967, Reinikainen 1967, 1968, Stone 1968, Huikari and Paavilainen 1972, Bergmann and Neubert 1976, Kolari 1979 and Binnas et al. 1980), whereas the anatomical symptoms have seldom been described (Blaser et al. 1967, Stone and Will 1965, de Lanuza 1966). The macroscopic and microscopic symptoms of growth disturbances have been described by Raitio and Rantala (1977), Kolari et al. (1977), Raitio (1979, 1981) and Kunelius (1982). The present summary on the symptoms of growth disturbances in pine is based on the mentioned investigations.

Symptoms

Macroscopic symptoms

The first external symptoms of growth disturbances are an extremely abundant resin flow and various disturbances in the apical dominance. Resin flow may be so powerful that the hardened resin will prevent the buds from opening in spring. Disturbances in the apical dominance are characterized by a poorly developed terminal bud (smaller than the lateral buds) or several equally strong buds at the tip of the leader.

In the worst cases the terminal bud and even the lateral buds have died or they do not exist at all. In such cases the meristems of fascicles start to form a number of new buds. The first visible external symptoms appear in buds of the leader and as the situation becomes worse also in the lateral shoots.

The improperly developed bud may devide into two, three or even four shoots. Forking may occur at any point of the leader. Abnormal apical dominance causes the formation of a multiple-leader tree. After the death of apexes and the development of buds from fascicles the tree top usually becomes a dense cluster of several short shoots. In some cases the internodes of the annual leader remain abnormally short (rosetting). Shortened internodes may occur for the whole length of the shoot or only at some parts. In addition to the before-described symptoms, the affected trees may display abnormal swelling of the leader, cracks reaching the pith and distortion of the shoot (bent, S-shaped). In extremely bad cases the leader is partly or completely dead. Furthermore the shoots may suffer from developmental disturbances i.e. growth starts normally in the spring but later ceases completely. By that time the new needles have not even had time to develop properly.

The needles in affected trees are usually partly deformed. Deformations are best seen at the tip of the leader. Affected needles are thick (disproportionately thick in relation to their length), dark green, spiral or hook shaped. The needles vary in length, often spreading wide apart. In some cases the needles of fascicles are not apart but as if glued by the tips to one another. The needles have often chlorotic or necrotic spots and bands. The fascicles have often three—four needles. Needle deformations often appear before any other external symptoms.

Microscopic symptoms

Browning of cells often occurs in the pith tissue of the leaders in the affected trees. Browning appears as small spots or in the worst cases the pith of the entire shoot is

brown. Browning usually starts below a dead apex.

Another clearly discernible symptom in the pith tissue is the formation of cavities. The cavities are surrounded by thinwalled hypertrophic cells, visible in the pith tissue even before the formation of cavities. Cavities and shrinking of bark have also been found in annual leaders.

Browning, death and cavities of cells occur also in buds at different developmental stages.

The most typical symptoms in the needles are the thin secondary walls of the schlerenchyma, overgrowth of cells, deformations of vascular bundles and different cavities.

There may be one or more cavities of different size. Almost without exception the cavities are in the schlerenchyma in the middle of the needle and in the worst cases may occupy the entire transfusion tissue. The first cavities appear at the tip and/or base of the needle i.e. in the meristems. Obviously, if the middle region of the intercalary meristem at the needle base becomes injured at different points of the growing season, cavities of various lengths along the length of the needle appear. If the cavity proceeds uninterrupted from the base to the tip of the needle, the middle regions of the meristem have been injured right at the start of the growing season or before it.

The schlerenchymatous cell walls of needles in affected trees are remarkably thinner than in healthy trees. The schlerenchymatous cell walls usually become thinner from the rounded side to the straight side of the needle so that they are thickest above the phloem and right at the upper edge of the rounded side and thinnest between the vascular bundles. In the needles of healthy trees these cells are a thick-walled schlerenchyma throughout.

Overgrowth of the parenchyma and schlerenchyma of the transfusion tissue occurs also often.

The phloem and xylem of the vascular bundles in healthy needles are almost invariably equally thick. Cells form straight rows and are almost even-sized. The phloem in the vascular bundles of the affected needles is remarkably larger than the xylem. Cells are in disarrangement and vary in size. At the edges of vascular bundles the xylem cells have shrunk and also an overgrowth of albuminous cells occurs in the phloem. The needles of affected trees have often three or four vascular bundles instead of two. The extra vascular bundles are in the middle of the schlerenchyma and nearly always formed of the xylem only. Injuries in vascular bundles as well as the weak secondary thickening of the schlerenchymatous cell wall appear earlier than the other microscopic symptoms of growth disturbances.

The primary phloem cells in roots are thin-walled and swollen. The vascular cylinder of the root has developed cavities and the protoxylem is poorly lignified.

The macroscopic symptoms of roots resemble those of the shoot. The death and forking of root tips result in a dense and short root bundle which is probably incapable of ensuring the uptake of water and nutrients for the shoot. A typical symptom is the dwarf roots and swelling towards the tip (Kunelius 1982).

Discussion

The assumption has been that a shortage of micronutrients, mainly of boron, causes growth disturbances (Huikari 1974). Nutrient shortage manifests itself as four different levels of symptoms (Bussler 1974):

1. On a physiological level when the deficiency symptoms are discernible as biochemical and/or submicroscopic internal structural changes of cells.
2. On an anatomical level when the deficiency symptoms are seen as a change in cell and tissue structure.
3. On a morphological level when the deficiency symptoms are visible both as internal and external structural changes.
4. As a death of plant parts or the whole plant.

On the basis of the macroscopic and microscopic symptoms described by Raitio and Rantala (1977) the trees suffering from growth disturbances can be classified as four groups according to their appearances:

1. Normal trees with possibly only physiological symptoms.
2. Normal-looking trees that already show microscopic symptoms (anatomical level).
3. Trees suffering from growth disturbances. Both microscopic and macroscopic symptoms are present (morphological level).
4. Completely dead trees.

These four groups should be considered especially in the nutritional investigations.

The macroscopic and microscopic symptoms resemble most those of boron deficiency. Boron deficiency typically causes the death of the leader, its tip or terminal bud, formation of secondary shoots and various disturbances in the apical dominance. Similarly, the macroscopic symptoms of needles and roots greatly resemble the boron deficiency symptoms encountered in conifers (see Kolari 1979). The described microscopic symptoms support the hypothesis on the causes of growth disturbances.

Although the shortage of copper and zinc in pine also leads to dieback, the symptoms such as pendulous shoots and branches as well as clearly marked apical chlorosis caused by a copper shortage, and the over-all chlorosis of needles and needle cast of older than 1—2-year old needles caused by a zinc shortage, are quite different from those encountered on peatland afforestation areas.

According to the symptoms and comparative nutrient analyses, it seems that the growth disturbances found in the afforestation areas of drained peatlands and old peatland fields are mainly caused by a boron shortage. However, the disturbances in the nurseries, although their symptoms resemble those encountered on peatlands, are probably caused by a micronutrient shortage brought on by both water and nutrient conditions. Preliminary studies suggest that the cause is an imbalance between nitrogen, iron, aluminum and boron or molybdenum.

Literature

BAULE, H. & FRICKER, C. 1967. Die Düngung von Waldbäumen. 260 s. Augsburg. Augsburger Druck- und Verlagshaus GmbH.

BERGMANN, W. & NEUBERT, P. 1976. Pflanzendiagnose und Pflanzenanalyse zur Ermittlung von Ernährungsstörungen und des Ernährungszustandes der Kulturpflanzen. 711 p. Jena. Gustav Fischer Verlag.

BINNS, W.O., MAYHEAD, G.J. & MacKENZIE, J.M. 1981. Nutrient deficiencies of conifers in British forests. An illustrated guide. 23 p. Forestry Commission.

BLASER, W., MARR, C. & TAKAHASHI, D. 1967. Anatomy of boron deficient *Thuja plicata*. Amer. J. Bot. 54(9):1107—1113.

BUSSLER, W. 1974. Microscopical and microchemical characteristics of deficiency diseases. In: Wehrman, J. (Ed.). Plant analysis and fertilizer problems. Vol. 1. Proceedings of 7th Int. Coll. on plant analysis and fertilizer problems. Hannover., p. 83—92.

GOSLIN, W.E. 1959. Effects of deficiencies of essential elements on the development and mineral composition of seedlings of Scots pine (*Pinus sylvestris* L.). Ph. D. thesis. Dept. of Botany. The Ohio State University.

HUIKARI, O. 1974. Hivenravinteet ja puiden kasvu. Metsä ja puu 11:24—25.

— & PAAVILAINEN, E. 1972. Metsän lannoitus. 68 s. Helsinki. Kirjayhtymä.

KOLARI, K. 1979. Hivenravinteiden puute metsäpuilla ja männyn kasvuhäiriöilmiö Suomessa. Kirjallisuuskatsaus. Abstract: Micro-nutrient deficiency in forest trees and dieback of Scots pine in Finland. A review. Folia For. 389:1—37.

— , PAAVILAINEN, E. & RAITIO, H. 1977. Männyn juuristosuhteista Kivisuon kasvuhäiriöalueella. Abstract: Pine root condition and growth disturbances. Folia For. 313:1—16.

KUNELIUS, K. 1982. Männyn kasvuhäiriöt metsitetyllä suopellolla ja ojitetulla rämeellä. Metsänhoitotieteen laudaturtyö yleistä metsätutkintoa varten. Helsingin yliopisto. Metsänhoitotieteen laitos. 82 p.

LANUZA, J.M. de. 1966. Nutrition hidroponica con microelementos I. Manganeso, boro y molibdeno en Pinus radiata. 399 p. Inst. For. Invest. Exp. Madrid.

RAITIO, H. 1979. Boorin puutteesta aiheutuva männyn kasvuhäiriö metsitetyllä suopellolla. Oireiden kuvaus ja tulkinta. Abstract: Growth disturbances of Scots pine caused by boron deficiency on an afforested abandoned peatland field. Description and interpretation of symptoms. Folia For. 412:1—16.

— 1981. Pääravinnelannoituksen vaikutus männyn neulasten rakenteeseen ja ravinnepitoisuuksiin ojitetulla lyhytkorsinevalla. Abstract: Effect of macronutrient fertilization on the structure and nutrient content of pine needles on a drained short sedge bog. Folia For. 456:1—10.

— & RANTALA, E-M. 1977. Männyn kasvuhäiriön makro- ja mikroskooppisia oireita. Oireiden kuvaus ja tulkinta. Summary: Macroscopic and microscopic symptoms of a growth disturbance in Scots pine. Description and interpretation. Commun. Inst. For. Fenn. 91(1):1—29.

REINIKAINEN, A. 1967. The appearance of nutrient deficiency in plants growing in the experimental area for forest fertilization at Kivisuo. Proceedings of the Colloquium on Forest Fertilization, Jyväskylä/Finland 1967:345—361. International Potash Institute, Bern/Switzerland.

— 1968. Ravinteiden puutosoireista puulajeilla. Teoksessa: Jamalainen, E.A. 1968. Kasvien puutostaudit. 128 s. Helsinki, Kirjayhtymä.

— & SILFVERBERG, K. 1983. Significance of whole-tree nutrient analysis in the diagnosis of growth disorders. Proc. of Int. Workshop on Growth Disturbances of Forest Trees in Jyväskylä, Finland, in 1982. (Printed in this Proceedings)

STONE, E.L. 1968. Microelement nutrition of forest trees. A review. In: Forest fertilization theory and practice. p. 132—175. Published by Tennessee Valley Authory National Fertilizer Development Center, Muscle Schoals, Alabama.

— & WILL, G.M. 1965. Boron deficiency in Pinus radiata and P. pinaster. For. Sci. 11(4):425—433.
VEIJALAINEN, H. 1975. Kasvuhäiriöistä ja niiden syistä metsäojitusalueilla. Summary: Dieback and fertilization on drained peatlands. Suo 26(5):87—92.
— 1977. Use of needle analysis for diagnosing micronutrient deficiencies of Scots pine on drained peatlands. Seloste: Neulasanalyysi männyn mikroravinnetilanteen määrityksessä turvemailla. Commun. Inst. For. Fenn. 92(4):1—32.

Total of 22 references

PHYSIOLOGICAL AND BIOCHEMICAL ROLE OF MICRONUTRIENTS IN GROWTH DISTURBANCES OF FOREST TREES

Kimmo K. Kolari

The paper considers micronutrient deficiencies (B, Cu, Fe, Mn, and Zn), their physiological and biochemical (metabolical) background and possible ways of interpreting the role of micronutrient deficiencies in the growth disturbances of forest trees. Some results of preliminary biochemical tests on Scots pine (*Pinus sylvestris* L.) from growth disturbance areas are presented and discussed.

Role of micronutrients in plant metabolism

Micronutrients such as boron, copper, iron, manganese and zinc are essential for plants. Although the amounts needed by the plants are very low (parts per million) they are essential for plant metabolism, because they (except for non-metallic boron) act as activators or regulators, or as structural parts of enzymes.

Physiological and biochemical research on plant mineral nutrition has demonstrated several direct or indirect metabolic roles of micronutrients in plants (Fig. 1), e.g. in photosynthesis (Cu, Fe, Mn, Zn), respiration (B, Cu, Fe, Mn), sugar metabolism (B, Cu, Zn), nitrogen and protein metabolism (B, Cu, Mn, Mo, Zn), cell differentation (B, Cu), secondary metabolism (B, Cu, Zn) including auxin metabolism (B, Cu, Zn) and lignification (B, Cu). (See general literature).

Changes in the micronutrient nutrition of plants, e.g. in their concentrations, in their mutual relation or in their relation to macronutrients may result in a deficiency of micronutrients (Olsen 1972). The deficiency first appears as biochemical changes in the cells, with subsequent malformation or death of cells and tissues leading to visual symptoms (Bussler 1974).

These disturbances in the metabolism may then (including the anatomical malformations of cells and tissues) result in a poor water economy, development and growth or even death of plant organs, increased susceptibility to frost, insect or fungal damage (Walker and Beacher 1963, Snowdon 1973, Albrektson et al. 1977).

Description of disorders at the metabolic level

The description of physiological and biochemical disorders in plants can be approached in two ways. One consists of the determination of known metabolic inter-

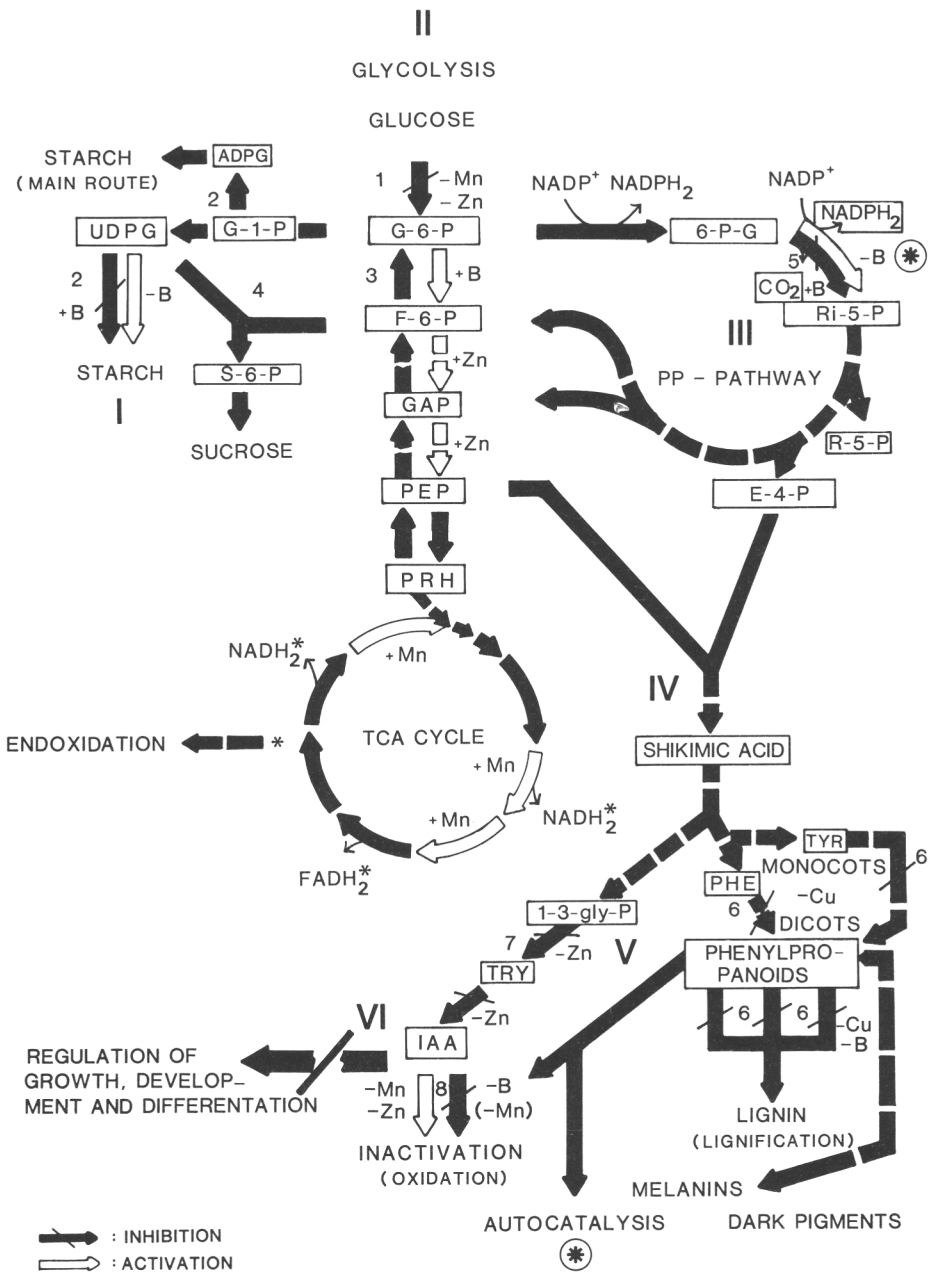


Figure 1. Role of micronutrients (B, Cu, Mn, Zn) in plant metabolism. A simplified scheme.

Legend: I = starch synthesis, II = glycolysis, III = pentose phosphate -pathway, IV = shicimic acid -pathway, V = phenyl-propanoid metabolism, VI = auxin metabolism

1 = hexokinase, 2 = starch synthase, 3 = glucose-phosphate isomerase (phosphoglucomutase), 4 = sucrose-phosphate synthase 5 = 6-phosphogluconate dehydrogenase, 6 = polyphenol oxidase, 7 = tryptophan synthase, 8 = IAA-oxidase (consists of several oxidases)

B = $B(OH)_4$, borate-ion, CO_2 = carbon dioxide, Cu = Cu^+, copper-ion, E-4-P = erythrose-4-phosphate, F-6-P = fructose-6-phosphate, $FADH_2$ = flavin adenine dinucleotide, GAP = glyseraldehyde-3-phosphate, G-1-P = glucose-1-phosphate, G-6-P = glucose-6-phosphate, IAA = indolyl-3-acetic acid, I-3-gly-P = indolyl-3-glyserine-phosphate, Mn = Mn^{++} and Mn^{+++}, manganese-ion, $NADH_2$ = nicotinamide adenine dinucleotide (reduced), $NADPH_2$ = nicotinamide adenine dinucleotide phosphate (reduced), NAD^+, $NADP^+$ = oxidized form, PEP = phosphoenolpyruvate, 6-P-G = 6-phosphogluconic acid, PHE = phenylalanine, PP = pentose-phosphate pathway, PRH = pyruvate (pyruvic acid) R-5-P = ribose-5-phosphate, Ri-5-P = ribulose-5-phosphate, SHK = citric acid cycle, S-6-P = sucrose-6-phosphate, TRY = tryptophane, UDPG = uridine diphosphate glucose, Zn = Zn^+, zinc-ion

mediates or end products (metabolite level), whose formation are known to be affected by the micronutrients in question. The other consists of the determination of the activity of enzymes involved in particular metabolic reactions (enzyme level), in which micronutrients of interest are known to act. Examples of metabolite level are compounds as starch, sugars, aromatic amino acids, phenolic compounds and auxins, and of enzyme level enzymes as starch synthase (UDPG-starch glucosyltransferase, E.C. 2.4.11), sucrose synthase (E.C. 2.4.1.13), glucose - 1 - phosphate uridylyltransferase (UDPG-pyrophosphorylase, E.C. 2.7.7.9), glucose-6-phosphate and phosphogluconate dehydrogenases (E.C. 1.1.1.49 and 1.1.1.44), monophenol mono-oxygenase (polyphenol oxidase, E.C. 1.14.18.1), tryptophane synthase (E.C. 4.2.1.20) and IAA-oxidase system (peroxidase function, E.C.1.11.1.7).

Physiological and biochemical tests

Determination of metabolite concentrations and enzyme activities combined with both foliar analysis and growth measurements represent one possible means of obtaining evidence about the micronutriental causes of growth disturbances of forest trees, although there will be problems in applying the methods to forest trees. So far, only a few metabolic disorders caused by micronutrient deficiencies have been studied in forest trees.

According to the literature, possible micronutrient deficiencies at the metabolic level may be solved on the basis of the following information about known (more or less specific) metabolic changes or disorders in conjunction with foliar (or tissue) analysis:

Starch and sugar metabolism:

- accumulation of starch or changes in the starch/sugar-ratio; boron deficiency (McIlrath and Palser 1956, Lee and Aronoff 1966, Augsten and Eichhorn 1976)
- accumulation of xylose; manganese deficiency (Bar-Akiva et al. 1967)
- decreased starch formation; zinc deficiency (Thorne 1957, Jyung et al. 1975)

Pentose-phosphate pathway and tricarboxylic acid cycle

- increased activity of glucose-6-phosphate or 6-phosphogluconate dehydrogenases (pentose-phosphate-pathway) during active growth period; boron deficiency (Lee and Aronoff 1967, Augsten and Hundt 1970, Shkolnik and Ilinskaya 1975).
- decreased activity of the intermediate reactions in the tricarboxylic acid (Krebs) cycle; manganese deficiency (Nason and McElroy 1963, Bonner and Varner 1965).

Nitrogen metabolism, aromatic amino acids and secondary metabolism

- nitrate-ion accumulation and decreased activity of nitrate reductase (E.C. 1.6.6.3); boron deficiency (Bonilla et al. 1980).
- accumulation of (aromatic) amino acids; boron, copper, iron, manganese or zinc deficiency (Hewitt 1963, Polykarpochina and Khavkin 1972, Bussler 1981)
- decreased activity of polyphenol oxidase or accumulation of phenolic acids (leading to poor lignin synthesis); copper deficiency (Flaig 1973, Rahimi and Bussler 1973, Bergman and Neubert (1976)
- accumulation of phenylpropanoids (also leading to poor ligning synthesis); boron deficiency (Perkins and Aronoff 1956, Lee and Aronoff 1967, Walker 1973, Shkolnik and Ilinskaya 1975)
- accumulation of auxins (indolyl-3-acetic acid, IAA); boron deficiency (Coke and Whittington 1968, Rajaratnam and Lowry 1975)
- decreased activity or inhibition of IAA-oxidase (by accumulatd phenolics); boron deficiency (Rabin and Klein 1957, Gortner and Kent 1958, Gortner et al. 1958, Coke and Whittington 1968, Shkolnik 1974)
- decreased synthesis of indolyl-3-acetic acid (IAA) via decreased tryptophan synthesis; zinc deficiency (Tsui 1948, Salami and Kenefick 1970).

Other more specific tests

- increased (manganese deficiency) and decreased (iron deficiency) peroxidase activity (Bar-Akiva 1961, 1971, Bar-Akiva et al. 1967, O'Sullivan et al. 1969)
- decreased carbonate dehydratase (carbonic anhydrase, E.C. 4.2.1.1) activity (photosynthetic carbon metabolism); zinc deficiency (Bar-Akiva and Lavon 1969, Edwards and Mohamed 1973, Randall and Bouma 1973)
- decreased activity of ascorbate oxidase (E.C. 1.10.3.3, redox-systems); copper deficiency (Perumal and Beattie 1966, Bar-Akiva et al. 1970).

Preliminary physiological and biochemical tests in growth disturbance research in Finland

The growth disturbance project has carried out some preliminary physiological and biochemical tests on Scots pine material of Kivisuo and Muhos areas from the control and growth disturbance stands (including both healthy looking and growth disturbed trees).

The preliminary tests showed that in the Kivisuo material (Experiment XIII) both the starch concentration and the starch/sucrose ratio in 1-year-old needles from the topmost shoots were higher in healthy looking trees but lower in growth disturbed trees on growth disturbance plots compared to control trees during the end of the height growth period (unpublished data). In the Muhos material (Experiment 33) no accumulation of IAA was found in the leading shoots of trees of growth disturbance stands during the middle of the height growth period and the IAA-concentration of the leaders of control trees was slightly higher (unpublished data).

The activity of 6-P-gluconate dehydrogenase was found to be highest in the buds of healthy looking trees on growth disturbance plots and lowest in the control trees during the resting period (see separate article by Pietiläinen in this Proceedings). In all cases the boron concentration of 1-year-old needles of the topmost shoots from the growth disturbance plots was significantly lower than in the control plot trees (1.7—4.6 ppm B vs. 8.1—30.3 ppm B).

These results indicate (excluding the IAA-analysis results as so far) that healthy looking trees in growth disturbance stands may suffer from physiological boron deficiency and that trees already showing growth disturbance symptoms were possibly recovering from boron deficiency due to a weakened but more balanced metabolism, which was also evident from retarded but symptomeless growth of the topmost shoots.

In future also the metabolism of phenolic compounds will be included in the research programme of the project.

Literature

General literature

Commission on Biochemical Nomenclature. 1973. Enzyme nomenclature. Recommendations (1972) of the International Union of Pure and Applied Chemistry and the International Union of Biochemistry. 443 p. Amsterdam. Elsevier.

EPSTEIN, E. 1972. Mineral nutrition of plants: principles and perspectives. 412 p. New York. John Wiley and Sons Inc.

GAUCH, H.G. 1972. Inorganic plant nutrition. Ch. 10: Roles of micronutrients in higher plants. Dowden. Hutchinson & Ross Inc., p. 239—279.

HEWITT, E.J. & SMITH, T.A. 1974. Plant mineral nutrition. 282 p. London. English Univ. Press.

KLIEGEL, W. 1980. Bor in Biologie, Medizin und Pharmagie: Physiologische Wirkungen und Anwendung von Borverbindungen. 900 p. Berling Heidelberg. Springer-Verlag.

MENGEL, K. 1972. Ernährung und Stoffwechsel der Planze. 470 p. Stuttgart. Gustav Frischer Verlag.

MORTVEDT, J.J., GIORDANO, P.M. & LINDSAY, W.L. (Eds.). 1972. Micronutrients in agriculture. 666 p. Madison Wisconsin, USA. Soil Sci. Amer. Inc.

NICHOLAS, D.J.D. & EGAN, A.R. (Eds.) 1975. Trace elements in soil-plant-animal systems. 417 p. New York Academic Press.

References

ALBREKTSON, A., ARONSSON, A. & TAMM, C.O. 1977. The effect of forest fertilization on primary production and nutrient cycling in the forest ecosystem. Silva Fenn. 11(3):233—239.

AUGSTEN, H. & HUNDT, M. 1970. Untersuchungen zum Einfluss des Bors auf den Atmungsstoffwechsel von *Helianthus annuus* L. Biol. Zbl. 89:497—505.

— & EICHHORN, M. 1976. Biochemie und Physiologie der Borwirkung bei Pflanzen. Biol. Rdsch. 14:268—285.

BAR-AKIVA, A. 1961. Biochemical indications as means of distinguishing between iron and manganese deficiencies in citrus plants. Nature 190:647—648.

— 1971. Functional aspects of mineral nutrients in use for the evaluation of plant nutrient requirement. In: R.M. Samish (ed.) Recent Advances in Plant Nutrition, Colloq. Tel Aviv 1970. Gordon and Breach. New York., p. 115—142.

— & LAVON, R. 1969. Carbonic anhydrase activity as a indicator of zinc deficiency in citrus leaves. J. Hort. Sci. 44:359—362.

— , KAPLAN, M. & LAVON, R. 1967. The use of a biochemical indicator for diagnosing micronutrient deficiencies of grape fruit trees under field conditions. Agrochimica 11 (3): 285—288.

— , LAVON, R. & SAGIV, J. 1970. Ascorbic acid oxidase activity as a measure of the copper nutrition requirement of citrus trees. Agrochimica 14(1): 47—54.

BERGMAN, W. & NEUBERT, P. 1976. Pflanzendiagnose und Pflanzenanalyse. Zur Ermittlung von Ernährungsstörungen und des Ernährungzustandes der Kulturpflanzen. Jena. VEB Gustav Fischer Verlag, p. 91—210.

BONILLA, J., CADAHÍA, C., CARPENA, O. & HERNANDO, V. 1980. Effects of boron on nitrogen metabolism and sugar levels of sugar beet. Plant and Soil 57: 3—9.

BONNER, J. & VARNER, J.E. 1965. The path of carbon in respiratory metabolism. In: Bonner, J. & Varner, J.E. (Eds.). Plant biochemistry. New York and London. Academic Press, P. 213—230.

BUSSLER, W. 1974. Microscopical and microchemical characteristics of deficiency diseases. In: Wehrman, J. (Ed.). Plant analysis and fertilizer problems. Vol. 1. Proc. 7th Int. Coll. on plant analysis and fertilizer problems. Hannover, p. 83—92.

— 1981. Physiological functions and utilization of copper. In: Loneragan et al. (Eds.). Copper in soils and plants. Sydney. Academic Press, p. 213—234.

COKE, L. & WHITTINGTON, W.J. 1968. The role of boron in plant growth. IV. Interrelationships between boron and indolyl-3-acetic acid in the metabolism of bean radicles. J. Exp. Bot. 19:295—308.

EDWARDS, L.G.E. & MOHAMED, A.K. 1973. Reduction in carbonic anhydrase activity in zinc deficient leaves of *Phaseolus vulgaris* L. Crop Sci. 13(3): 351—354.

FLAIG, W. 1973. Bedeutung von Mikroelementen bei der Bildung und Umwandlung aromatischer Verbindungen in der Pflanze. Agrochimica 17(1—2)11—43).

GORTNER, W.A. & KENT, M.J. 1958. The coenzyme requirement and enzyme inhibitors of pineapple indoleacetic acid oxidase. J. Biol. Chem. 233:731—735.

— , KENT, M.J. & SUTHERLAND, G.K. 1958. Ferulic and p-coumaric acids in pineapple tissue as modifiers of pineapple indoleacetic acid oxidase. Nature 181:630—631.

HEWITT, E.J. 1963. Essential nutrient elements for plants. In: Steward, F.C. (Ed.). Plant physiology. Vol III. Inorganic plant nutrition. New York. Academic Press, p. 137—360.

JYUNG, W.H., EHMANN, A., SCHLENDER, K.K. & SCALA, J. 1975. Zinc nutrition and starch metabolism in *Phaseolus vulgaris* L. Plant physiol. 55:414—420.

LEE, S.G. & ARONOFF, S. 1966. Investigations of the role of boron in plants. III. Anatomical observations. Plant physiol. 41:1570—1577.

— & ARONOFF, S. 1967. Boron in plants: A biochemical role. Science 158:798—799.

McILRATH, W.J. & PALSER, B.F. 1956. Responses of tomato, turnip and cotton to variations in boron nutrition. I. Physiological responses. Bot. Gaz. 118:43—52.

NASON, A. & McELROY, N.D. 1963. Modes of action of the essential mineral elements. In: Steward, F.C. (Ed.). Plant Physiology III. Academic Press, p. 451—536.

OLSEN, S.R. 1972. Micronutrient interactions. In: Mortvedt et al. (Eds.). Micronutrients in agriculture. Madison, USA. Soil Sci. Soc. Amer. Inc., p. 243—246.

O'SULLIVAN, M., FLYNN, M.J. & CODD, F.J. 1969. A biochemical method for diagnosing micronutrient deficiencies in plants. Ir. J. Agric. Res. 8(1):111—119.

PERKINS, H.J. & ARONOFF, S. 1956. Identification of the blue-fluorescent compounds in boron deficient plants. Arch. Biochem. Biophys. 64:506—507.

PERUMAL, A. & BEATTIE, J.M. 1966. Effect of different levels of copper on the activity of certain enzymes in leaves of apple. Proc. Ano. Soc. Hort. Sci. 88:41—47.

POLYKARPOCHINA, R.T. & KHAVKIN, E.E. 1972. [The role of zinc in nitrogen metabolism of growing cells]. Fiziol. Rast. 19(3):597—603.

RABIN, R.S. & KLEIN, R.M. 1957. Chlorogenic acid as a competetive inhibitor of indoleacetic acid oxydase. Arch. Biochem. Biophys. 79:11—15.

RAHIMI, A. & BUSSLER, W. 1973. Physiologishe Voraussetzungen für die Bildung der Kupfermangelsymptome. Z. Pfl. Ernähr. Bodenk. 136(1): 25—32.

RAJARATNAM, J.A. & LOWRY, J.B. 1974. The role of boron in the oil-palm (*Elais guineensis*). Ann. Bot. 38:193—200.

RANDALL, P.J. & BOUMA, D. 1973. Zinc deficiency, carbonic anhydrase and photosynthesis in leaves of spinach. Plant physiol. 52(3):229—232.

SALAMI, A.V. & KENEFICK, D.G. 1970. Stimulation of growth in zinc deficient corn seedlings by the addition of tryptophan. Crop. Sci. 10:291—294.

SHKOLNIK, M.YA. 1974. [General conception of the physiological role of boron in plants.] Fiziol. Rast. 21(1):174—186.

— & ILINSKAYA, N.L. 1975. [Effect of boron deficiency on the activity of glucose-6-phosphate dehydrogenase in plants with different boron requirements.] Fiziol. Rast. 22(4):801—805.

SNOWDON, P. 1973. Problems in the diagnosis of boron deficiency in *Pinus radiata.* FAO/IUFRO Int. Symp. For. Fert. Paris 3—7 Dec. 1973, p. 1—5.

THORNE, W. 1957. Zinc deficiency and its control. Adv. Agron. 9:31—65.

TSUI, C. 1948. The role of zinc in auxin synthesis in the tomato plant. Amer. J. Bot. 35:172—179.

WALKER, J.R.L. 1973. Positive feedback mechanisms and plant disease. Mauri Ora 1:137—140.

WALKER, L.C. & BEACHER, R.L. 1963. Fertilizer response with forest trees in North America. Nat. Plant. Food Inst. Washington D.C.

Total of 49 references

DIAGNOSTICAL USE OF NEEDLE ANALYSIS IN GROWTH DISTURBED SCOTS PINE STANDS

Antti Reinikainen and Heikki Veijalainen

Two comparisons between the needle analyses of normal and disordered Scots pines have been discussed. There were no significant differences between the micronutrient contents of trees with visible growth disturbances and normal-looking pines in the same stands. The normal-looking trees had lower N values than disturbed trees. The above-mentioned pines with visible disorders were compared with samples taken from non-disordered areas. This comparison indicated that the disordered stands had higher contents of N, P and K and lower of B than normal stands. Boron level of disordered stands indicated B deficiency. By means of mentioned differences the stands with disorder risk became needle analytically distinguishable from the normal ones.

Introduction

Chemical needle analysis has been used in peatland forest research since 1967 in Finland. Most of the work has been concerned with Scots pine stands. The determination of the nutrient status and the prediction of the nutrient requirements of tree stands (nutritional diagnosis) has become everyday research routine as far as the macronutrients in young pine forests are concerned (Paarlahti et al. 1971).

In peatland stands, PK and NPK fertilization, as well as other growth increasing measures in general, decrease the micronutrient content of the needles (Veijalainen 1977). This phenomenon, which is mainly due to the so-called dilution effect, but sometimes also to antagonistic or synergistic relationships between nutrients, makes it difficult to interpret the results of micronutrient analysis. In addition, information concerning the behaviour of the micronutrients in the current needles as a function of time, position and tree age, and other factors important for interpretation (see e.g. Paarlahti et al. 1971), is sparse. In spite of these and other unsolved problems, needle analysis is considered to give basic information about stands which show acute growth anomalies.

Foliar analysis has recently been used in Finland as a diagnostical method in growth disturbance areas by many researchers (e.g. Huikari 1974, 1977, Raitio 1978, 1979, 1981, Kolari and Veijalainen 1981, Silfverberg 1980, 1982). In addition, Kolari (1979) has reviewed a number of papers dealing with micronutrient deficiencies in forest trees, and critical deficiency levels for B, Cu, Mn, Zn and Fe in pine needles. Such a limit for the boron content was preliminarily determined for Scots pine in Finnish peatland sites, too. Needle analysis has also been used in order to clarify the efficiency of micronutrient fertilization, and to study for how long are the responses to micronutrient fertilizations still detectable by this technique (Veijalainen 1977, 1980). Micronutrient analysis has occasionally been used also in practical forestry in Finland in order to improve the fertilization recommendations.

The lack of comparative foliar analysis results from normal and disordered stands became immediately apparent at the start of the growth disturbance project, initiated by the Finnish Forest Research Institute in 1976.

The aim of this study was to find out whether there are any differences between the foliar nutrient contents of normal,

externally normal and disordered pine stands growing on drained peatlands and, to a certain extent, to evaluate the diagnostical importance of the observed differences.

Mrs. Riitta Heinonen, M.Sc., has helped us with the computer analysis. We are much obliged to her for her assistance.

Material and methods

Needle samples were collected in March 1977 from 45 disordered pine stands growing on ditched and in most cases fertilized peatlands (Fig. 1). The needle samples from the disordered pines in each stand were taken from the south-facing, uppermost living branches, or in the case of die-back, from the highest, living substituting shoot. Each sample consisted of current needles from 5 or 6 pines.

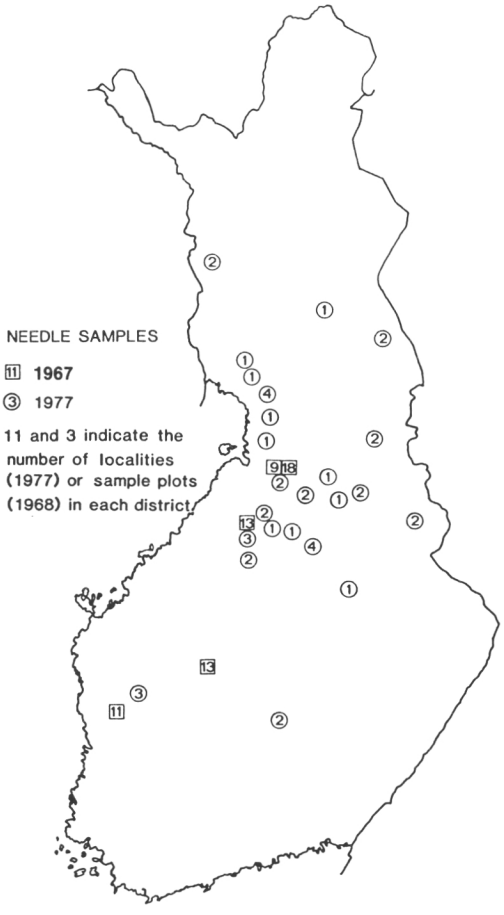


Figure 1. Location of the needle sampling points and number of sampled stands in each area.

At the same time, 45 needle samples were collected from healthy looking pines of about the same age and size as the disordered pines, growing in the growth disturbance patches or in the immediate vicinity. The sampling method presented by Paarlahti et al. (1971) was used.

The needle material for the macronutrient analysis of normal stands (n=191) representing sites completely free from growth disturbances, was collected in 1967 from 17 peatland fertilization experiments in different parts of Finland (Fig. 1). Samples were taken from plots which had received different fertilization treatments and also from the unfertilized plots (see Paarlahti et al. 1971). This material comprised the results of 64 B and Mn analyses. Additional Cu (n=123) and Zn (n=88) analyses were conducted during the period 1969—79. They represent healthy pine stands chiefly from southern Finland.

The N, P, K, Ca, Mg, B, Cu, Mn, Zn contents of the needle samples were analysed by Viljavuuspalvelu Oy (= Soil Testing Service Co.). The nutrient contents were expressed on the basis of dry weight as well as the biomass of 100 needles.

Results

When the results of the needle analysis of the die-back and normal-looking trees from the same sites were compared, it was apparent that there were no great differences as regards nutrient contents between these tree group ($\bar{x} \pm t_{.05} \cdot S_{\bar{x}}$):

	Normal-looking pines	Die-back pines
N %	1.66 ± 0.07	1.76 ± 0.07
P mg/g	1.95 ± 0.10	2.03 ± 0.10
K "	5.73 ± 0.26	5.81 ± 0.32
Ca "	2.19 ± 0.15	2.27 ± 0.14
Mg "	1.52 ± 0.06	1.47 ± 0.05
B ppm	6.6 ± 1.5	6.0 ± 1.4
Cu "	4.6 ± 0.2	4.4 ± 0.2
Mn "	296 ± 33	310 ± 46
Zn "	56 ± 2	54 ± 2
g/100 needles	1.82 ± 0.10	1.91 ± 0.15

The die-back pines had quite high N, P, K, Ca and Mn contents in their needles, but so had the normal-looking pines, too. This "accumulation" of macronutrients in growth disturbance stands may indicate that the trees suffered from a certain physiological dissarrangement. According to Paarlahti et al. (1971), the macronutrient levels were slightly supra-optimal.

The boron contents in both groups were below the critical deficiency level (7—10 ppm) apart from 4 areas. Only one of the areas had a clear phosphorus deficiency (P=1,2 mg/g). This and four areas with high boron contents were omitted from the following discriminant analysis.

When discriminant analysis was applied to the paired samples (n=80) in order to determine whether there were multiple differences between the nutrient contents of the needles in normal-looking and die-back pines, only nitrogen was entered (F=6,51). 65 % of the cases were classified correctly after this step. On the other hand, when growth and biomass parameters were used as additional criteria, two "populations" without any overlapping were distinguished. The eight discriminating factors included needle Mg. To find a logical explanation for this result requires further study. The highest F-value (83,0) was for height growth per five years.

To sum up, the results indicate that there were no other deficiencies commonly present in the two compared materials than B deficiency.

Differences in the dry weight of the needles were quite small, even though the die-back material contained both small and very large needles (0.80—2,97 g/100 needles). The range in the normal-looking stands was more narrow (1,13—2,63 g/100 needles). Of the needle nutrients, phosphorus, potassium and boron were positively and zinc negatively correlated with needle-weight to a significant degree.

The comparison between material from normal (1967) and growth disturbance stands (1977) made it clear that the disordered pines had higher concentrations of N, P and K but lower concentrations of B than the healthy stands (Fig. 2a-c, and 3). No great differences were detected as regards the Ca, Mg, Cu, Zn or Mn values. Regarding to the Cu and Zn values the comparison was based on a new reference material (see page 45), because the Zn values in the earlier material (Paarlahti et al. 1971) have proved to be erraneous and Cu analysis was omitted at that time. Both elements had higher contents in the disordered stands than in healthy stands (Fig. 4a-b).

These results are most likely due to the

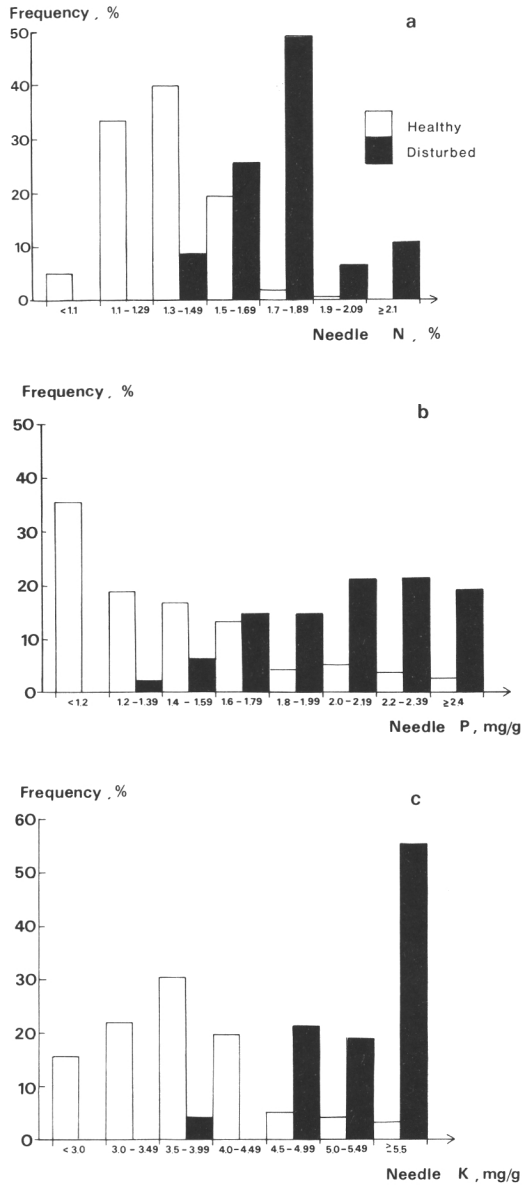


Figure 2 a—c. Distributions of macronutrient contents in healthy and disturbed stands.

different sites and different nutritional status of the soil in the compared materials. However, at the same time a rough indication is obtained of the nutrient levels at which the risk of growth disturbances is high. Macronutrient deficiencies were quite general in the normal material (N < 1,3 %, P < 1,7 mg/g and K < 4,0 mg/g). No nitrogen deficiency was observed in the

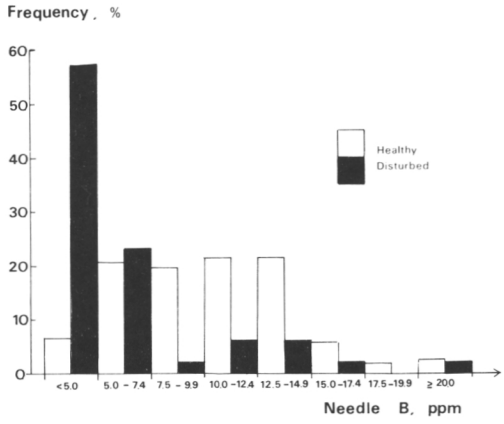


Figure 3. Distribution of boron content in healthy and disturbed stands.

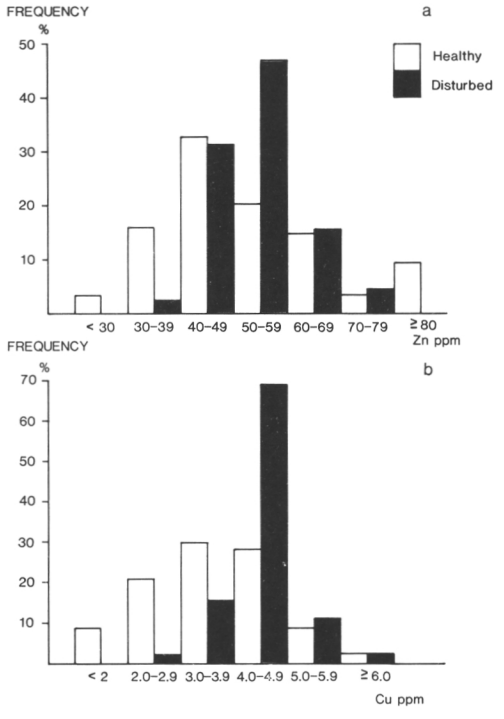


Figure 4 a—b. Distributions of copper and zinc contents of healthy and disturbed stands.

growth disturbance areas and only in a few sites there were mild phosphorus or potassium deficiencies evident.

About 80 per cent of the disordered stands had boron values of less than 7,5 ppm. This only gives a hint that boron deficiency may have caused most of the diebacks. One way of proving whether boron deficiency is really a reason for these growth disturbances is to carry out boron fertilization experiments. Some results from such experiments and other research work in this field have been discussed elsewhere in this Proceedings.

Discussion

The ability of needle analysis to indicate whether a certain nutrient is a limiting growth factor varies from one element to another. The current needle nitrogen, phosphorus and potassium contents of pines growing on peatlands show correlations suitable for diagnostic purposes, but needle calcium and magnesium contents, for instance, do not appear to have functions which would make them valuable in the determination of the critical levels of these elements (Paarlahti et al. 1971).

Needle samples were taken from quite fertile peatland sites which in most cases were fertilized (PK or NPK fertilization). Consequently, low boron values mostly were due to the dilution effect and did not directly indicate the boron status of the site (Veijalainen 1977). On the other hand, the low boron values are common in growth disturbance areas (Huikari 1974, Kolari 1979, Silfverberg 1980), the visual symptoms are those of boron deficiency (Kolari 1979) and in some cases an early boron fertilization has prevented or partly cured the syndrome.

Consequentely, needle boron contents have a crude diagnostical value by dividing growth disturbance areas into two groups:

a. stands with low boron content
b. stands with average or high boron content

In the a-group, which is characterized also by raised macronutrient contents refertilization without boron or unfavourable ecological conditions may bring out boron deficiency but in the b-group reasons for dieback are of other origin. Of course the needle analysis has its limitations and, for example, the boron values may alter according to the stage of disorder.

The role of the other micronutrients studied here (Cu, Mn, Zn) still remains obscure from the viewpoint of disorders.

Copper, at least, appears to be deficient in some of the peatland sites as observed in agriculture (see Kurki 1972), but its contribution to the causes of growth disturbances is less probable.

Literature

HUIKARI, O. 1974. Hivenravinteet ja puiden kasvu. (Micro-nutrients and tree-growth.) Metsä ja Puu 11/1974.

— 1977. Micro-nutrient deficiencies cause growth disturbances in trees. Silva Fenn. 3:251—255.

KOLARI, K. 1979. Hivenravinteiden puute metsäpuilla ja männyn kasvuhäiriöilmiö Suomessa. Kirjallisuuskatsaus. Abstract: Micro-nutrient deficiency in forest trees and dieback of Scots pine in Finland. A review. Folia For. 389:1—37.

— VEIJALAINEN, H. 1981. Boorin, kuparin ja kalkin vaikutus rauduskoivun alkukehitykseen kasvuhäiriöalueen turpeella. Summary: Effect of boron, copper and calcium on the initial growth of *Betula pendula* on peat from a growth disturbance area. Metsäntutkimuslaitoksen suontutkimusosaston tiedonantoja 31:1—26.

KURKI, M. 1972. Suomen peltojen viljavuudesta II. Über die Fruchtbarkeit des finnischen Ackerbodens auf der in Jahren 1955—70 durchgeführten Bodenfruchtbarkeitsuntersuchungen. 182 p. Helsinki.

PAARLAHTI, K., REINIKAINEN, A. & VEIJALAINEN, H. 1971. Nutritional diagnosis of Scots pine stands by needle and peat analysis. Seloste: Maa- ja neulasanalyysi turvemaan männiköiden ravitsemustilanteen määrityksessä. Commun. Inst. For. Fenn. 74 (5): 1—58.

RAITIO, H. 1978. Pääravinnelannoituksen vaikutus männyn neulasten rakenteeseen ja ravinnepitoisuuksiin karulla avosuolla. Parkanon tutkimusaseman tiedonantoja 7. 9 p.

— 1979. Boorin puutteesta aiheutuva kasvuhäiriö metsitetyllä suopellolla. Oireiden kuvaus ja tulkinta. Abstract: Growth disturbances of Scots pine caused by boron deficiency on an afforested abandoned peatland field. Description and interpretation of symptoms. Folia For. 412:1—16.

— 1981. Pääravinnelannoituksen vaikutus männyn neulasten rakenteeseen ja ravinnepitoisuuksiin ojitetulla lyhytkorsinevalla. Abstract: Effect of macronutrient fertilization on the structure and nutrient content of pine needles on a drained short sedge bog. Folia For. 456:1—10.

SILFVERBERG, K. 1980. Kuusen kasvuhäiriö ja hivenravinteet. Abstract: Micronutritional growth disorder in Norway spruce. Folia For. 432:1—13.

— 1982. Näringsanalys i två spårämnesgödslade granplanteringar. Abstract: Nutrient analysis of Norway spruce after application of micronutrients. Folia For. 526:1—12.

VEIJALAINEN, H. 1977. Use of needle analysis for diagnosing micronutrient deficiencies of Scots pine on drained peatlands. Seloste: Neulasanalyysi männyn mikroravinnetilanteen määrityksessä turvemailla. Commun. Inst. For. Fenn. 92(4):1—32.

— 1980. Eräiden hivenlannoitteiden käyttökelpoisuus suometsien lannoituksessa. Neulasanalyysiin perustuva tarkastelu. Summary: Usability of some micronutrient fertilizers in peatland forests. Report basing on needle analysis. Folia For. 443:1—15.

Total of 13 references

SIGNIFICANCE OF WHOLE-TREE NUTRIENT ANALYSIS IN THE DIAGNOSIS OF GROWTH DISORDERS

Antti Reinikainen and Klaus Silfverberg

The biomass and nutrient distribution of Scots pine was studied in three peatland stands suffering from growth disorders. The amount of branch biomass increased at the expense of stem growth, especially, during the syndrome sequence: normal — acute dieback — chronic dieback — revival. Nutrient analysis of tree compartments revealed that macronutrients have accumulated in the needle biomass and that the micronutrients were rather evenly distributed in the biomass. The presumed deficiencies of micronutrients were, in partly, better diagnosed by examining the nutrient ratios and distribution.

Introduction

Causal analysis of the growth disorders observed and studied in Finland, has been based on a hypothesis about the role of micronutrients, first published by Huikari (1974). The description (Veijalainen 1975, Raitio and Rantala 1977, Kolari 1979) and site-ecological analysis of the syndrome (Veijalainen 1978) had progressed to such an extent by 1977, that the cases selected in this study could be identified as the growth disorder in question.

There were three reasons for examining the distribution of biomass and nutrients in disordered pines, in addition to the earlier diagnostic approach based mainly on internal and external symptoms, needle and peat analyses, as well as some site characteristics (e.g. Huikari 1977). The reasons were as follows: (1) It appeared to be necessary to complete the disorder descriptions. (2) The changed biomass distribution was presumed to be important for the development and maintenance of the disorder, and also for the revival of the tree. (3) A certain analogy between the biomass and nutrient distributions is obvious. However, whole tree nutrient analyses seemed to be particularly applicable in disorder cases, because certain nutritional features were observed already in simple needle analyses (Paarlahti et al. 1971, Veijalainen 1977, Raitio and Rantala 1977, Braekke 1977a, Albrektson et al. 1977).

Material and methods

The material was collected from three Scots pine stands growing on peatland sites which were suffering from a growth disorder. The study sites are located in *Kivisuo*. Leivonmäki (61°51'N, 25°59'E), *Alkkia* Karvia (62°12'N, 22°18'E), and Holopansuo, *Vieremä* (63°51'N, 26°59'E).

The Kivisuo site (Experiment I, see Huikari and Paarlahti 1973) is an afforested peat harvesting field, originally an open cottongrass bog with *Sphagnum fuscum*. The Alkkia site (experiment 39, see Kaunisto 1976) is an afforested field originally cleared on a *Sphagnum fuscum* bog, sanded and limed during the cultivation period before 1963. The Vieremä site was originally a cottongrass sedge pine bog, drained in 1964 and fertilized in 1970.

The sample trees were selected at Kivisuo in August 1976, and at Alkkia and Vieremä in October 1977. At Kivisuo only biomass was sampled.

The trees were first classified and the sample trees selected according to this classification. Four different stages were distinguished: *normal trees* (symbol No) which had maintained their leaders and apical dominance, *acute dieback trees* (A) which were affected by an apical disorder in the current year leaders, *chronic disorder trees* (Ch) which had suffered from apical diebacks during two or more successive years, and *reviving trees* (R) which had succeeded in correcting the dieback during the previous 1—2 years. A total of 55 sample trees were selected.

The above-ground biomass of the sample trees was determined according to the principles presented e.g. by Hakkila (1971) and Mälkönen (1974). The following parameters were measured: (1) dry-weight of five components of the above-ground biomass, namely stem with bark, branches with bark, and needles divided into three age classes, current year, one year old, and older, (2) height (leader) and diameter growth during the last 5...7 years retrospectively.

Samples were formed from the Alkkia and Vieremä sample trees in the following way for the chemical analyses: equal subsamples were taken from the different biomass compartments of each sample tree and combined to form a sample representing one site and one disorder class. Thus, for instance, there was one sample for the current needles of chronic disorder trees at Alkkia. Needle samples were taken from three branches at different heights in the crown. Branchwood was sampled from the same branches such that pieces taken at three different distances (base, middle and tip) from the trunk were combined. The stemwood samples consisted of the discs sawn at two heights (1,3 m and 75 % of the height). All the samples were homogenized before analysis. There are two important sources of error in the nutrient contents arising from the sampling method. (1) the mixed samples of stem- and branchwood cannot represent either the vertical variation of nutrient contents or the wood/bark ratios correctly. The needle samples are more reliable. (2) the results of nutrient analysis are statistically dumb values.

Combining the subsamples in this way is widely used in needle analysis studies and in practice (see Paarlahti et al. 1971, Veijalainen 1977).

The nutrient analyses were carried out in the laboratory of Viljavuuspalvelu Oy (Soil Testing Service Co.) by the same standard methods used for the material of Paarlahti et al. (1971). Total contents of N, P, K, Ca, Mg, Mn, Fe, Zn, B and Cu were determined as a percentage, mg/g or ppm of dry-matter.

Results

Distribution of standing biomass

The biomass distribution in different disorder classes was compared (Table 1). Despite considerable variation within each of the groups compared, a clear trend was evident during the syndrome sequence (No → R). The percentage of stemwood continually decreased and the proportion of branch-

wood increased. The needle biomass appeared to decline either in the acute or in the chronic stage. The proportions of different needle age classes varied during the syndrome sequence. Before the onset of the disorder, the high needle biomass was rather evenly distributed between the age classes. In acute trees the current needles minimum was observed. In revived trees, the proportion of needles increased partly due to their revival and partly because the amount of branches and shoots had increased. It was also evident that there had been anomalies in the biomass distribution already before the outbreak of the terminal diebacks.

Table 1. Amount and distribution of above ground biomass in the sample trees at Alkkia, Vieremä and Kivisuo sites.

Site	Disorder stage			
	Normal	Acute	Chronic	Reviving
Alkkia	(n=4)	(n=4)	(n=5)	(n=4)
biomass (g)	5707	7574	4422	6044
needles (%)	34,6	24,7	25,2	37,2
current	15,0	11,8	14,1	17,1
1 year	11,5	7,4	6,9	12,7
older	8,1	5,5	4,2	7,4
branches (%)	27,5	34,1	36,8	30,0
stem (%)	37,9	41,2	38,0	32,7
Vieremä	(n=6)	(n=6)	(n=6)	(n=6)
biomass (g)	4875	7484	6037	10244
needles (%)	21,3	19,4	17,6	16,2
current	7,2	5,7	8,0	6,6
1 year	6,2	10,1	6,3	6,1
older	7,9	3,6	3,3	3,5
branches (%)	23,7	34,4	35,3	40,2
stem (%)	55,0	46,2	47,1	43,6
Kivisuo	(n=6)		(n=8)	
biomass (g)	14704	—	15834	—
needles (%)	21,5		22,7	
current	8,3		7,1	
older	13,2		15,6	
branches (%)	27,5		32,4	
stem (%)	50,9		44,9	

The extent to which the normal trees on the disorder sites differed from the pines of symptomless sites was examined by comparing their biomass distribution (Table 2). They deviated from the reference trees of the nearest age class in that trees on the disorder sites, even the normal ones, had a smaller stem biomass and a larger needle biomass, respectively.

Development of the biomass distribution

Changes in the biomass of three compartments only were measured: height growth and radial growth (Tables 3 and 4) over a period of five years, as well as the current shoot production. Height growth did not decrease 2—5 years before the onset of dieback, but was depressed during the acute and chronic stages, and did not reach the level of the normal trees during the short revival period. Radial growth was at a high level before the onset of dieback as a result of fertilization. A decline occurred after dieback, although the ring width remained at a rather high level. It almost reached the level before dieback during the revival stage. Thus there was a clear difference between the development of height growth and radial growth during the syndrome sequence. The altered stem growth relations led to the development of a thick-butted stem form which is said to be typical for disorder trees (Huikari 1974, Veijalainen 1975).

The change in biomass allocation during the progression of the syndrome was followed by studying the current production of needles and shoots in relation to other biomass compartments. Needle and shoot production was highest in the reviving trees, but its

Table 2. The biomass distribution of the normal-looking trees at three disorder sites as compared to that for normal Scots pine stands in northern Europe.

Tree character	Alkkia (No)	Ovington (1957)	Braekke (1977b)	Kivisuo (No)	Vieremä (No)	Mälkönen (1974) 1.	3.	2.	Bringmark (1977)
Age, years	13	17	20	21	22	28	45	47	120-150
Total biomass g/tree	5707	6270	10070	14704	4875	6163	53458	49633	155470
Stem, %	37,9	46,8	59,1	50,9	55,0	64,5	80,2	72,6	78,9
Branches, %	27,5	25,6	26,5	27,6	23,7	22,6	14,0	19,0	14,6
Needles, %	34,6	27,6	14,4	21,5	21,3	12,9	5,8	8,4	6,6

Table 3. Average height growth (with $S_{\bar{x}}$) of the sample trees at the disorder sites.

	Height growth, cm			
Site/Time	No	A	Ch	R
Alkkia				
1977	47± 3,9	10± 6,5	6± 2,6	36± 3,0
1976	44± 5,7	36± 5,0	18± 7,8	33± 3,1
1973-77	210±21,0	188±12,0	130± 7,4	166±12,6
Vieremä				
1977	29± 1,6	18± 4,6	11± 4,0	24± 4,7
1976	35± 2.9	32± 4,6	22± 5,5	28± 1,3
1973-77	160± 9,1	149±18,9	89±12,6	130± 9,9
Kivisuo				
1972-76	205±24,3	—	123±20,5	—

Table 4. Average radial growth (with ($S_{\bar{x}}$) of sample trees at the disorder sites.

	Radial growth, mm			
Site/Time	No	A	Ch	R
Alkkia				
1977	4,7±0,2	3,1±0,6	2,9±0,4	3,9±0,5
1976	4,9±0,5	4,3±0,6	3,0±0,5	3,6±0,6
1973-77	18,0±1,6	23,1±1,7	17,5±1,6	18,1±2,3
Vieremä				
1977	2,3±0,4	2,4±0,7	1,9±0,3	3,0±0,5
1976	3,3±0,5	3,3±0,5	2,6±0,4	3,1±0,3
1973-77	16,1±1,9	17,6±2,4	13,4±1,4	17,8±2,3
Kivisuo				
1972-76	18,3±2,5	—	17,7±1,67	—

relative proportion reached the maximum values during the chronic stage. The syndrome appeared to increase the number of apical growing points and the so-called growth mantle area in branches (see e.g. Laasasenaho 1978). At the same time the increasing amount of green biomass produced a decreasing amount of stemwood.

Nutrient pattern

Two approaches were used in handling the nutrient data. (1) The nutrient contents of the biomass components were examined separately. (2) The amounts of nutrients in each measured biomass compartment were determined from the content values, and the distributions as well as the nutrient consumption per biomass unit were then calculated.

Needle nutrients

The current needles had very similar contents of the major nutrients (Tables 5 and 6) regardless of the symptom stage. The ranges of N (1,34—1,51 %), P (1,55—1,94 mg/g) and K (5.01—5.99 mg/g) were in good agreement with the optimum determined for Scots pine growing on peat (Paarlahti et al. 1971). Thus, the values are rather high on average, but only a few cases resembled a certain increase in the major nutrient levels that was earlier observed on disorder sites (Raitio & Rantala 1977, Paavilainen 1978).

There were two different groups among the micronutrients. Mn and Fe were significantly higher than the mean values presented by Paarlahti et al. (1971) and as high as those reported by Veijalainen (1977). Zn, B and Cu took the following levels: Zn was intermediate or low, Cu values were low, nearing the deficiency level in normal and acute trees of Vieremä, 2,4 ppm (cf. Haveraaen 1964), and B was completely inside the deficiency level remaining, however to some extent higher than the minimum values (1,0—3,0 ppm) earlier observed in northern sites (Paarlahti et al. 1971, Huikari 1974, Albrektson et al. 1977, Braekke 1977b). The only regular pattern of micronutrient variation in the syndrome sequence was that the minimum values of critical nutrients mainly fell upon the acute stage (B at Alkkia, Zn and Cu at Vieremä).

As the macronutrient contents were moderate and the micronutrient contents did not fall to very low levels, the examination of micro/macro ratios was a task of special interest (see e.g. Raitio & Rantala 1977, Kolari et al. 1977). Those ratios were examined which presumably are capable of depicting the wellknown nutritional interactions (Olsen 1972, cit. Veijalainen 1977). The references were picked from the Finnish material concerning Scots pine growing on peatlands (Paarlahti et al. 1971, Veijalainen 1977). Only fertilized and normal stands were accepted. Certain B and Cu ratios were, on the average, significantly lower than those quoted in the references (Table 7). The differences in the ratios were relatively greater than those in the contents alone. The ratios B/Ca at Alkkia and Cu/N, Cu/P and Zn/P at Vieremä were significantly lower in the acute stage than the mean values of the other stages.

Table 5. Nutrient contents of different tree compartments and disorder stages at Alkkia.

Nutrient	Needles												Branches				Stem			
	Current				1-year old				Old											
	No	A	Ch	R	No	A	Ch	R	No	A	Ch	R	No	A	Ch	R	No	A	Ch	R
N %	1,43	1,37	1,51	1,51	1,29	1,40	1,51	1,40	1,23	1,23	1,43	1,32	0,38	0,33	0,38	0,39	0,16	0,18	0,16	0,20
Pmg/g	1,71	1,55	1,69	1,59	1,34	1,49	1,53	1,38	1,38	1,21	1,35	1,25	0,41	0,35	0,47	0,43	0,29	0,22	0,25	0,29
K "	5,40	5,40	5,70	5,99	4,91	5,20	5,21	4,91	4,12	4,32	4,52	4,52	2,06	1,67	1,77	2,06	1,17	0,98	1,17	1,37
Ca "	2,71	3,59	3,17	3,23	3,99	6,09	4,62	4,82	6,14	8,56	6,17	5,79	1,71	2,38	2,71	1,97	1,15	1,21	1,00	1,50
Mg "	1,36	1,31	1,42	1,45	1,18	1,31	1,42	1,36	1,03	1,23	1,27	1,15	0,59	0,65	0,70	0,67	0,41	0,41	0,40	0,48
Mn ppm	304	336	401	402	478	504	640	570	651	765	749	657	81	98	108	119	43	54	71	109
Fe "	249	188	258	140	176	214	175	146	185	186	186	184	139	164	178	136	76	80	94	—
Zn "	56	44	53	56	65	53	58	54	67	64	61	58	24	27	30	30	17	15	17	—
B "	3,9	3,4	4,5	4,5	4,0	3,8	4,3	4,6	4,4	3,9	4,9	5,7	5,0	4,9	6,7	6,5	3,6	3,8	3,4	3,9
Cu "	3,8	4,3	4,5	4,0	4,0	3,8	3,8	3,8	3,1	3,8	3,1	3,5	4,3	4,3	3,9	4,3	2,8	2,5	2,3	—

Table 6. Nutrient contents of different tree compartments and disorder stages at Vieremä.

Nutrient	Needles												Branches				Stem			
	Current				1-year old				Old											
	No	A	Ch	R	No	A	Ch	R	No	A	Ch	R	No	A	Ch	R	No	A	Ch	R
N %	1,43	1,34	1,44	1,34	1,37	1,37	1,48	1,37	1,26	1,34	1,43	1,34	0,37	0,36	0,23	0,31	0,15	0,21	0,19	0,19
Pmg/g	1,70	1,94	1,82	1,69	1,51	1,51	1,63	1,57	1,32	1,32	1,44	1,34	0,47	0,35	0,43	0,30	0,34	0,43	0,30	0,34
K "	5,60	5,50	5,01	5,40	5,11	5,11	4,51	4,91	4,52	4,22	4,12	4,32	1,67	1,28	0,88	0,98	0,98	1,12	0,98	0,88
Ca "	2,61	1,85	2,35	2,09	3,23	3,23	3,38	3,00	5,05	4,06	4,56	4,26	2,17	1,65	2,18	1,91	1,12	1,09	1,06	0,99
Mg "	1,45	1,25	1,43	1,40	1,35	1,35	1,47	1,14	1,12	1,19	1,22	1,04	0,70	0,52	0,65	0,56	0,45	0,39	0,44	0,40
Mn ppm	515	429	591	461	733	733	862	662	945	786	971	971	139	125	195	184	103	92	102	98
Fe "	102	118	106	125	162	162	132	229	154	116	182	156	164	126	139	168	142	142	108	140
Zn "	50	39	42	44	48	48	30	32	48	39	27	90	34	20	30	21	21	17	29	14
B "	5,5	4,8	4,5	4,9	5,6	5,6	4,1	5,0	5,0	4,4	4,4	3,8	4,9	4,8	4,0	4,9	4,1	4,0	3,8	3,1
Cu "	2,4	2,4	3,3	3,3	3,0	3,0	3,0	2,6	2,6	2,4	3,1	2,3	3,3	3,5	3,5	3,3	2,0	2,5	2,3	2,3

Table 7. Micronutrient/macronutrient ratios in different disorder stages at Vieremä and Alkkia. Statistical differences calculated by paired t-tests: symbols in the left column = differences to normal references, symbols in A column = differences between acute phase and the average for the site.

		No	A	Ch	R
Vieremä	**B/Ca	0.0021	0.0026	0.0019	0.0023
	***B/K	0.00098	0.00087	0.00089	0.00091
	*Cu/N	0.00017	0.00018*	0.00023	0.00025
	*Cu/P	0.0014	0.0012*	0.0018	0.0019
	Cu/Zn	0.0480	0.0615	0.0786	0.0750
	°Zn/P	0.0294	0.0203*	0.0231	0.0260
Alkkia	***B/Ca	0.0014	0.0009*	0.0014	0.0014
	***B/K	0.00072	0.00063°	0.00079	0.00075
	Cu/N	0.00027	0.00031	0.00027	0.00026
	°Cu/P	0.0022	0.0028	0.0027	0.0025
	Cu/Zn	0.0679	0.0977	0.0849	0.0714
	Zn/P	0.0327	0.0284	0.0314	0.0352

There were no marked differences between the two sites as regards the nutrient distribution between different needle age classes (Tables 5 and 6). Major nutrients N, P, K, and Mg decreased regularly from current to older needles, P most distinctly. The trend for Ca was clearly the opposite. The observed trends agreed mainly with those presented earlier (Leyton & Armson 1955, Madgwick 1964, Mälkönen 1974, Paavilainen 1980). A proper comparison showed that in disorder trees the fall in the P and K content especially was smaller than that in the reference trees on average. As regards the N values, the materials for peatland sites (the present one and that of Paavilainen 1980) deviated from the others in that nitrogen was evenly distributed between the needle age classes.

The micronutrient contents varied more irregularly between the needle age classes except for Mn, which was convergent with Ca. The Mn level of the current needles was already rather high but was, approximately half that of needles on the 3rd year (see Paavilainen 1980). Fe was also concentrated to some extent in the older needles.

The results for Mn and Fe thus agreed rather well with earlier observations concerning conifers (Ahrens 1964 and Stone's 1968 references, Kreutzer 1972). The Zn, Cu and B levels varied more irregularly, and to a smaller extent, between the needle age classes than did Mn and Fe. Cu was slightly concentrated in younger needles, but Zn and B showed an opposite trend in both two sites. Compared to the results of Ahrens (1964) and Paavilainen (1980), the most noticeable anomaly was that at Alkkia, where B was concentrated in the older needles.

Nutrient contents of non-green compartments

The content of each of the analyzed nutrients was at its lowest level in the stem samples on both sites, and in almost all the syndrome stages (Tables 5 and 6). It should be taken into account that the stem values include both wood and bark from the samples, as described in page 49.

The contents of major nutrients and Mn in the stems very clearly differed from the needle nutrient values, the latter being in most cases 5—8 times higher than those in the stems. N was most distinct in this respect. Stem Ca and Mg deviated to a considerably less extent from the corresponding values for the needles.

The micronutrients Fe, Zn, B and Cu were present in the stems at slightly lower levels than in the needles. They thus differed quite clearly from the case for the major nutrients and Mn. There were some examples where the nutrient contents were similar in all the compartments (Fe at Vieremä).

The nutrient contents of the branches fell regularly between the needle and stem values. The major nutrients and Mn were

Table 8. The average content of nutrients per unit above-ground biomass at Alkkia and Vieremä compared to Scots pine references for northern Europe. Ps=Peatland site.

Site/Author	Alkkia Ps				Brække (1977b)	Vieremä Ps				Lehtonen (1978)	Mälkönen (1974)	Ovington & Madgwick (1959)	Tamm (1956)	Holmen (1964)	Mälkönen (1974)	Mälkönen (1974)	Paavilainen (1980) 0 Ps	Paavilainen (1980) 2×NPK Ps
Stand age	13				20	22				25	28	33	39	44	45	47	100+	100+
	No	A	Ch	R		No	A	Ch	R									
N %	0.63	0.52	0.58	0.72	0.42	0.46	0.48	0.43	0.43	0.23	0.30	0.18	0.28	0.29	0.26	0.20	0.43	0.45
P mg/g	0.75	0.57	0.67	0.77	0.4	0.62	0.63	0.59	0.52	0.45	0.3	0.2	0.3	0.3	0.3	0.2	0.43	0.49
K "	2.7	2.2	2.5	3.1	1.6	2.0	1.9	1.6	1.6	1.2	1.5	1.1	1.2	1.1	1.1	1.0	1.4	1.5
Ca "	2.3	2.7	2.4	2.7	2.0	1.9	1.7	1.8	1.7	2.2	2.2	1.3	1.0	1.8	1.2	1.3	1.5	2.1
Mg "	0.7	0.7	0.8	0.9	0.5	0.7	0.6	0.7	0.6	0.4	—	0.3	—	0.4	—	—	0.51	0.53
Mn ppm	192	175	199	262	86	258	186	250	222	—	—	—	—	—	—	—	130	140
Fe "	140	137	158	—	89	147	136	123	152	—	—	—	—	—	—	—	—	—
Zn "	35	29	32	—	—	30	23	27	20	—	—	—	—	—	—	—	30	31
B "	4.1	4.1	5.2	5.0	—	4.6	4.5	4.0	4.1	—	—	—	—	—	—	—	5	3
Cu "	3.5	3.5	3.3	—	—	2.4	2.9	2.9	2.8	—	—	—	—	—	—	—	2	2

nearer the stem nutrient level. In some cases the B and Cu level in both sites even slightly exceeded the levels of the corresponding values in needles (Tables 5 and 6).

The macronutrient contents of the non-green parts absolutely and in relation to green parts were in rough agreement with presented earlier results (Ovington & Madgwick 1959, Mälkönen 1974, Lehtonen 1978, Paavilainen 1980).

Nutrient accumulation and distribution

The total binding of nutrients per unit above-ground biomass was calculated to the reference values (Table 8). The consumption of the macronutrients N, P, and K was found to be higher in disorder trees than in the reference trees of similar age classes. The comparison between nutrient and biomass distribution (Figs. 1 and 2) showed that this

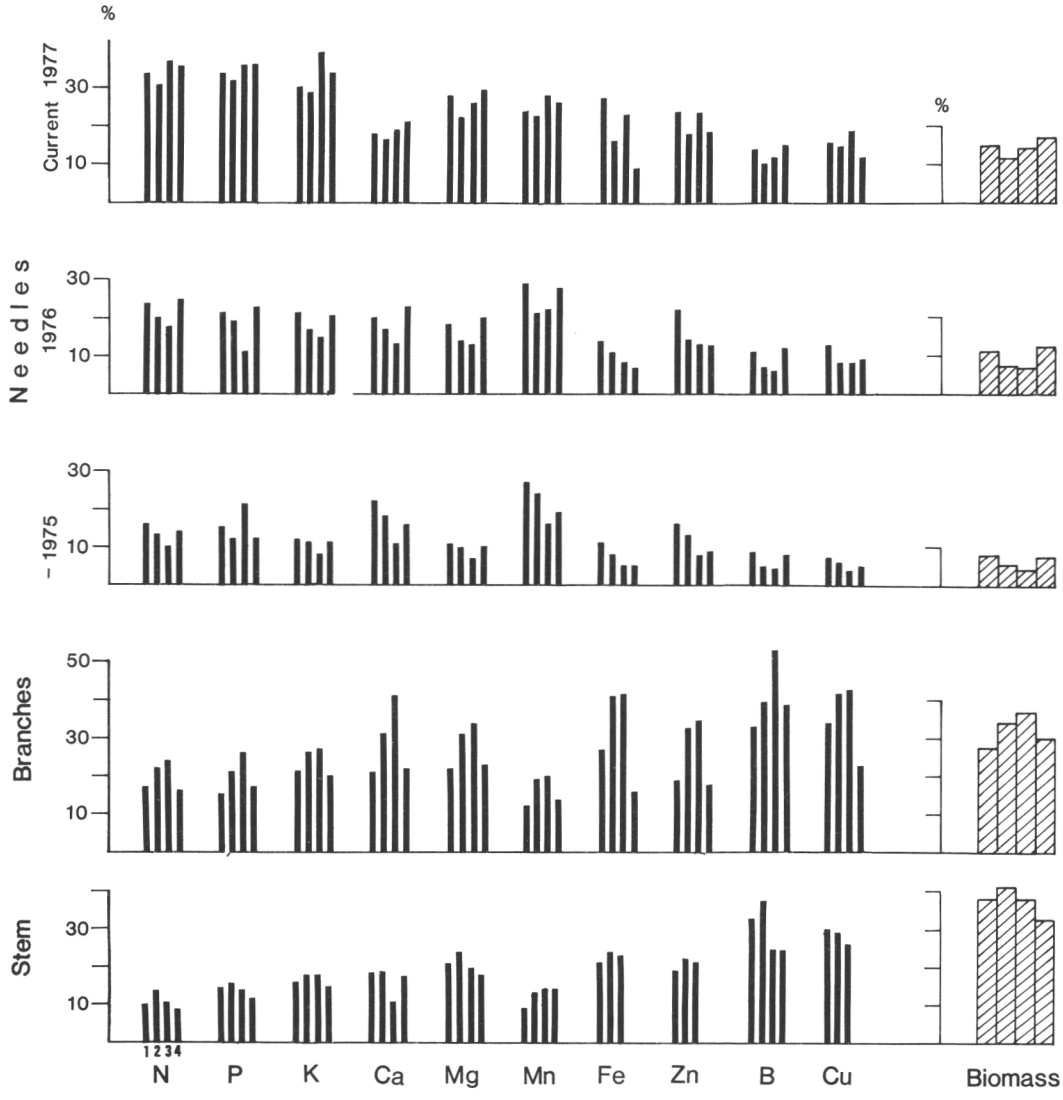


Figure 1. Percentage distribution of nutrients in the sample trees at Alkkia compared to the biomass distribution. The groups of pillars from left to right: 1 = normal, 2 = acute, 3 = chronic, 4 = reviving trees.

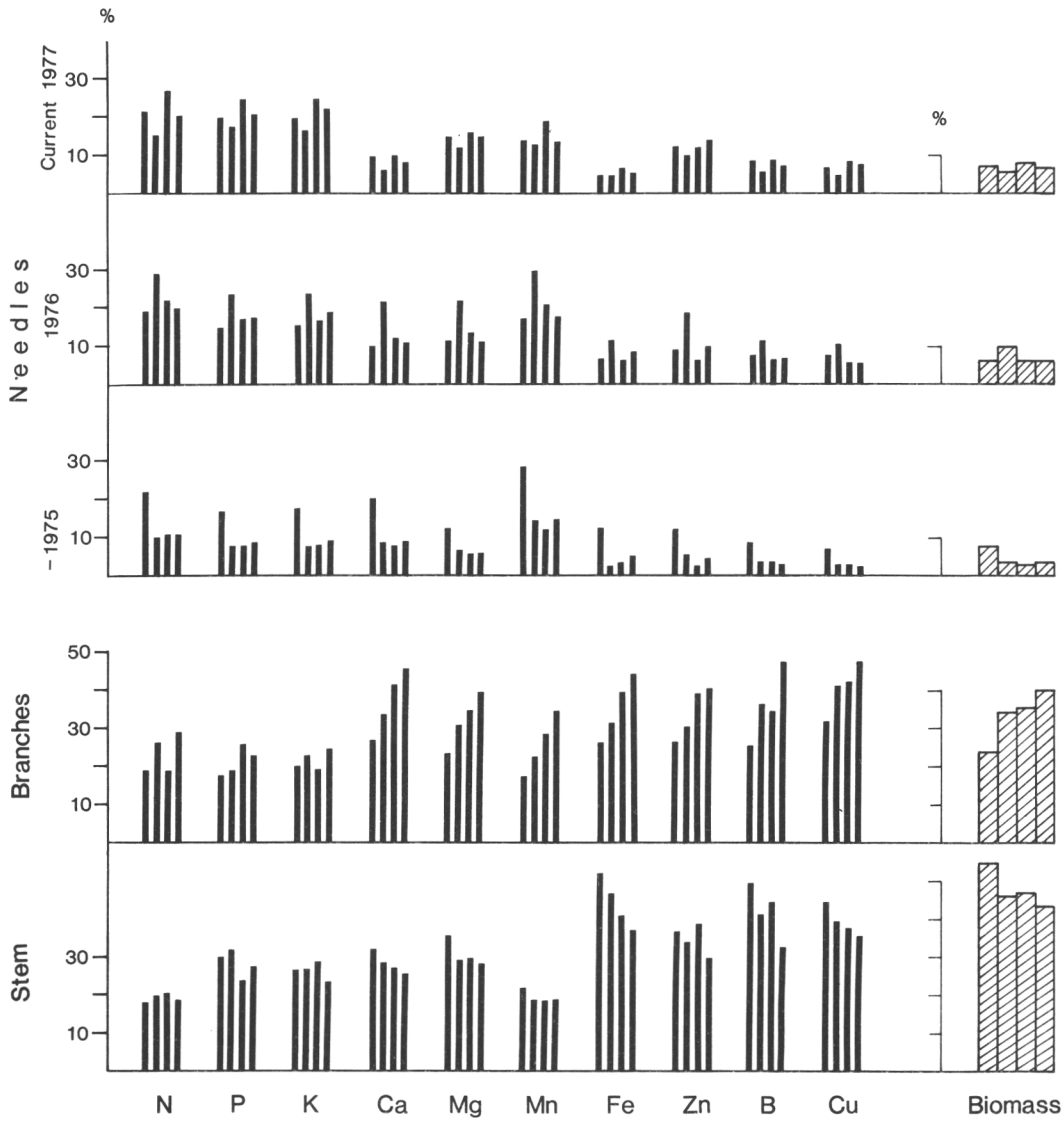


Figure 2. Percentage distribution of nutrients in the sample trees at Vieremä compared to the biomass distribution. Explanations: see Figure 1.

was due to the high proportion of needles and branches in the biomass of the disorder trees.

The relationship between biomass production and nutrient consumption was examined by calculating the ratio percentage of nutrient/percent of biomass. The value was 2,5—3,5 for the macronutrients in the needles, and only 0,3—0,6 for the stems, respectively. The needle micronutrients had values of around 1, B and Cu at the lowest level, in some cases 0,8—0,9 in the current needles of acute and chronic disorder trees. Correspondingly, B and Cu had the highest ratios, as much as 1,5—1,6 in the branches. Thus there were three types (Figs. 1 and 2) of nutrient distribution in the biomass: (1) the macronutrients N, P, K, (2) Ca, Mg and micronutrients Mn, Fe and Zn, (3) micronutrients Cu and B.

Concluding remarks

The most commonly used method for diagnosing the nutritional causes of growth disorders has been simple needle analysis. Owing to the problems encountered in explaining certain suspected deficiencies, the question arises of whether better information could be obtained by analysing other tree compartments or even the whole tree. The material available for examining this question is quite limited. The analyses from two fertilized peatland disorder sites are compared here to the reference values for comparable Scots pine sites.

Optimal macronutrient values, and critical levels of B and Cu were found by interpreting traditional needle analysis results. The ratios (B/K, B/Ca, Cu/N and Cu/P) were better indicators of deficiencies than the micronutrient contents.

The nutrient contents of other aboveground compartments and the distribution of total nutrients agreed rather well with the reference values. This means that the macronutrients were concentrated in the needles, but the micronutrients were evenly distributed throughout the tree. Slight accumulation of all nutrients in older needles, and micronutrients in the branches, was found to be typical of disorder trees.

The total consumption of macronutrients per unit dry-matter appeared to be higher in disorder trees than in reference trees. This high consumption, possibly typical of fertilized stands in general, was mainly due to the abundant needle biomass of disorder trees. It concerned both the nutrients given in fertilizers and others. On the other hand, the consumption of micronutrients per unit needle biomass was low.

Whether the hints obtained in this short examination are relevant from the viewpoint of diagnosing growth disorders or the nutrient budget of disordered stands requires further study. In any case, it seems that the analysis of whole-tree nutrients is of only very restricted applicability in diagnosis. A firm physiological background is needed before any progress can be made and better working models of nutrient dynamics will make the method more useful for research purposes.

Literature

AHRENS, E. 1964. Untersuchungen über den Gehalt von Blättern und Nadeln verschiedener Baumarten an Kupfer, Zink, Bor, Molybdän und Mangan. Allg. Forst- und Jagdzeitung 135. Heft 1:8—16.

ALBREKTSON, A., ARONSSON, A. & TAMM, C-O. 1977. The effect of forest fertilization on primary production and nutrient cycling in the forest ecosystem. In: Nutrient cycle in tree stands — Nordic symposium. Silva Fenn. 11(3):201—257.

BRAEKKE, F.H. 1977a. Fertilization for balanced mineral nutrition of forest on nutrient-poor peatland. Lyhennelmä: Turvemaiden tasapainoinen lannoitus. Suo 28(3):53—61.

— 1977b. Growth and chemical composition of Scots pine on nutrient-deficient peat after drainage and fertilization. Vekst og biomasse i furubestand på grøftet og gjødslet næringsfattig myr. Medd. Nor. inst. skogforsk. 33(8):289—305.

BRINGMARK, L. 1977. A bioelement budget of an old Scots pine forest in Central Sweden. In: Nutrient cycle in tree stands — Nordic symposium. Silva Fenn. 11(3):201—257.

HAKKILA, P. 1971. Coniferous branches as a raw material source. A sub-project of the joint nordic research programme for the utilization of logging residues. Tiivistelmä: Havupuun oksat raaka-ainelähteenä. Yhteispohjoismainen hakkuutähdetutkimuksen alaprojekti. Commun. Inst. For. Fenn. 75(1):1—60.

HAAVERAAEN, O. 1964. Koppermangel hos gran. Summary: Copper deficiency on Norway spruce. Tidsskr. Skogbr. 72(3):289—300.

HOLMEN, H. 1964. Forest ecological studies on drained peatland in the province of Uppland, Sweden. Parts I—III. Sammanfattning: Skogsekologiska studier på dikad torvmark i Uppland. Del I—III. Studia Forest. Suecica 16:1—236.

HUIKARI, O. 1974. Hivenravinteet ja puiden kasvu. Metsä ja Puu 11:24—25.

— 1977. Micro-nutrient deficiencies cause growth-disturbances in trees. In: Nutrient cycle in tree stands — Nordic symposium. Silva Fenn. 11(3): 201—257.

— & PAARLAHTI, K. 1973. Kivisuon metsänlannoituskokeet. Kenttäopas, 2 painos. Helsinki.

KAUNISTO, S. 1976. Alkkian kenttäkokeet 1961—1975. Metsäntutkimuslaitoksen Parkanon tutkimusaseman tiedonantoja 4.

KOLARI, K.K. 1979. Hivenravinteiden puute metsäpuilla ja männyn kasvuhäiriöilmiö Suomessa. Kirjallisuuskatsaus. Abstract: Micronutrient deficiency in forest trees and dieback of Scots pine in Finland. A review. Folia For. 389:1—37.

— , PAAVILAINEN, E. & RAITIO, H. 1977. Männyn juuristosuhteista Kivisuon kasvuhäiriöalueilla. Abstract: Pine root condition and growth disturbances. Folia For. 313:1—16.

KREUTZER, K. 1972. Die Wirkung des Mangan-mangels auf die Farbe, die Pigmente und den Gaswechsel von Fichtennadeln (Picea abies Karst.) Forstwiss. Cbl. 91(2):80—98.

LAASASENAHO, J. 1978. Puun ja metsikön kasvatusta ja kasvutuotoksesta Metsä ja Puu 12:12—14.

LEHTONEN, I. 1978. Ravinteiden kierto eräässä männikössä: IV Fytomassan ja ravinteiden määrä.

Summary: Nutrient cycle in a Scots pine stand: IV The amount of phytomass and nutrients. Silva Fenn. 12(1):47—55.
LEYTON, L. & ARMSON, K.A. 1955. Mineral composition of the foliage in the relation to the growth of Scots pine. For. Sci. 1:210—218.
MADGWICK, H.A.I. 1964. Variations in the chemical composition of Red Pne *(Pinus resinosa* Ait.) leaves: a comparison of well-grown and poorly grown trees. Forestry 37(1):87—94.
MÄLKÖNEN, E. 1974. Annual primary production and nutrient cycle in some Scots pine stands. Seloste: Vuotuinen primäärituotos ja ravinteiden kiertokulku männikössä. Commun. Inst. For. Fenn. 84(5):1—87.
OLSEN, S.R. 1972. Micronutrient interactions. In: Mortvedt, J.J. et al. (Eds.). 1972. Micronutrients in agriculture. Madison. USA. Soil Sci. Soc. Amer. Inc., p. 243—246.
OVINGTON, J.D. 1957. Dry-matter production by Pinus silvestris L. Ann. Bot. N.S. 21:287—314.
— & MADGWICK, H.A.I. 1959. Distribution of organic matter and plant nutrients in a plantation of Scots pine. For. Sci. 5:344—355.
PAARLAHTI, K., REINIKAINEN, A. & VEIJALAINEN, H. 1971. Nutritional diagnosis of Scots pine stands by needle and peat analysis. Seloste: Maa- ja neulasanalyysi turvemaiden männiköiden ravitsemustilan määrityksessä. Commun. Inst. For. Fenn. 74(5):1—58.
PAAVILAINEN, E. 1980. Effect of fertilization on plant biomass and nutrient cycle on a drained dwarf shrub pine swamp. Seloste: Lannoituksen vaikutus kasvibiomassaan ja ravinteiden kiertoon ojitetulla isovarpuisella rämeellä. Commun. Inst. For. Fenn. 98(5):1—71.
RAITIO, H. & RANTALA, E-M. 1977. Männyn kasvuhäiriön makro- ja mikroskooppisia oireita. Oireiden kuvaus ja tulkinta. Summary: Macroscopic and microscopic symptoms of a growth disturbance in Scots pine. Description and interpretation. Commun. Inst. For. Fenn. 91 (1):1—30.
STONE, E.L. 1968. Microelement nutrition of forest trees. A review. In: Forest fertilization theory and practice. p. 132—175. Published by Tennessee Valley Authority National Fertilizer Development Center, Muscle Schoals, Alabama.
TAMM, C.O. 1956. Studier över skogens näringsförhållanden. IV. Effekten av kalium och fosfor tillförsel till ett oväxtligt bestånd på dikad myr. Summary: Studies in forest nutrition. IV. The effects of supply of potassium and phosphorus to a poor stand on drained peat. Medd. Stat. Skogsf. Inst. 46:1—27.
VEIJALAINEN, H. 1975. Kasvuhäiriöistä ja niiden syistä metsäojitusalueilla. Summary: Dieback and fertilization on drained peatlands. Suo 26(5):87—92.
— 1977. Use of needle analysis for diagnosing micronutrient deficiencies of Scots pine on drained peatlands. Seloste: Neulasanalyysi männyn mikroravinnetilanteen määrityksessä turvemailla. Commun. Inst. For. Fenn. 92(4):1—32.
— 1978. Metsäpuiden latvakadon esiintymisestä Suomessa. Metsä ja Puu 2:31.

Total of 31 references

COMPARISON OF PIXE METHOD AND CHEMICAL ANALYSIS IN MEASUREMENT OF NEEDLE SAMPLES FROM GROWTH DISTURBANCE SCOTS PINE TREES

Taisto Raunemaa, Juha Samela and Riitta Erkinjuntti

In this study a comparison of the PIXE method to atomic absorption spectrometry or spectrophotometric method has been performed in analyzing pine needle samples. The samples have been collected from growth disturbance trees by the Finnish Forest Research Institute. The comparison includes the elements aluminum, silicon, phosphorus, potassium, calcium, manganese, iron and zinc. Other elements have also been measured but only by one method. From the comparison elements the values for silicon, phosphorus, potassium, calcium and manganese agree well when analyzed by PIXE and by chemical method. Reasons for observed deviations among other elements are discussed.

Introduction

The use of Particle Induced X-ray Emission (PIXE) started in the 1970's with the appearance of advanced X-ray semiconductor detectors and increased number of low energy accelerators (Willis et al. 1977). Its applicability to the elemental analysis of different sample materials has been widely investigated (Johansson 1981). The use which

at first was directed towards air pollution analysis has later been extended to biological and medical samples. The method is presently employed in several fields routinely. At the same time basic improvements of the method bring forward new possibilities.

The most widely used methods in the elemental analysis of biological samples are atomic absorption spectroscopy, spectrophotometry and neutron activation. At the Department of Physics, the University of Helsinki, the PIXE method has been employed for the purpose. When comparing the results given by the PIXE method to those by atomic absorption spectroscopy and photometric methods some general aspects can be exploited. The PIXE method gives in on measurement the concentration of several elements, and these values support each other. In atomic absorption spectroscopy and spectrophotometry different procedure must be applied for each element. The sensitivity, which can be adjusted separately for each element in the chemical methods, is not, however, always reached in the single PIXE measurement. No sensitivity adjustment in PIXE analyses was in these experiments effected. In the following atomic absorption spectroscopy and spectrophotometry will be called chemical methods.

The pine needles used as sample material in the comparison study belong to series of experiments carried out by the Finnish Forest Research Institute in the research on growth disturbance (Kolari 1979, Silfverberg 1980). The present comparison serves therefore also for a limited investigation on growth disturbance. Elemental analysis of this material was performed earlier by chemical methods (Veijalainen 1977).

The sample material

The sample material consisted of half a year old pine needles (*Pinus sylvestris* L.). The needles originate in two fertilization stands at Muhos (the experiments 33 g and 209). The stand areas were 100 m² (33 g) and 400 m² (209).

In the experiment 33 g both sound (T) and growth disturbed (H) trees had been fertilized. The treatments by NPK had been performed in 15.6.1972. The needles were collected from the growth in 1980, i.e. about eight years after fertilization. The needle material from the experiment 33 g includes also samples from untreated tree stands (Table 1).

The samples in the experiment 209 originate in unfertilized stands with the exception of 162 T, which sample originates in an ash-fertilized stand. The wet ash fertilization was performed in 1974.

All needle material was homogenized and ground to coarse powder. This powder was then used in chemical analyses. For the PIXE analyses the powder was ground fine to comply with the routine technique in PIXE work. After grinding the particle diameter was less than 80 μm. About 100 mg of the powder was compressed to a pellet in a polyacetalene ring. The sample irradiation was performed at the Accelerator Laboratory of the University of Helsinki on average three days after pellet preparation. In the meantime samples were stored in separate boxes in a dry storeroom at room temperature. Pellet properties do not change noticeably during storage. Only one PIXE determination was performed in each sample.

Table 1. Fertilization of the sample stands.

Sample	Fertilization	Date
	Experiment 33 g Stand area 100 m²	
2H, 2T	NPK 14 % N : 14 % P : 14 % K; 800 kg/10000 m² = NPK1	15.6.1972
6H, 6T	Unfertilized	
8H, 8T	NPK 14 % N : 14 % P : 14 % K; 800 kg/10000 m² fine ground = NPK2	15.6.1972
11H, 11T	Urea (contains N) and PK; 200 kg/10000 m² and 24—15 kg/10000 m²	15.6.1972
12H, 12T	NPK2	15.6.1972
18H, 18T	Unfertilized	
19H, 19T	NPK1	15.6.1972
22H, 22T	Urea 200 kg/10000 m² and PK 500 kg/10000 m²	15.6.1972
28H, (28T)	Urea 200 kg/10000 m² and PK 500 kg/10000 m²	15.6.1972
29H, (29T)	Unfertilized	
30H, 30T	NPK1	
	Experiment 209 Stand area 400 m²	
4	Unfertilized	
8	Unfertilized	
20	Unfertilized	
162T	Ash 40 700 kg/10000 m² (wet)	28.8.1974

Experimental procedure

Chemical analysis

The chemical analyses were performed at the Finnish Forest Research Institute's laboratory at Muhos.

The sample material which was first homogenized by coarse grinding, was then heated in 550 °C for 3—16 hours. The resulting ash was dissolved in 5 ml of 20 per cent hydrochloric acid and diluted by distilled water to 25 ml. The elements Mg, Al, K, Ca, Mn, Fe, Cu and Zn were determined from the diluted solution by using the atomic absorption method. Quantitative determinations were based on calibrations with standard solutions.

From the other elements silicon (Si) was analyzed by extracting the ash with 20 per cent hydrochloric acid. The resulting extract was dried and weighed for silicon determination. Phosphorus (P) was determined by the vanadomolybdate-method (Kemira Co.'s standard method, modified by Pekka Pietiläinen and Anna-Liisa Mertaniemi, Muhos Research Station). In this method the study solution was mixed with 5 ml of vanadomolybdate reagent and diluted to 25 ml. The determination of phosphorus was made by color dispersive spectrophotometry at 400 nm wavelength. Nitrogen (N) analysis was performed using the Kjeldahl-method and 630 nm wavelength. Boron (B) was determined by the atsomethine-method and with the wavelength 410 nm.

The PIXE method

The particle induced X-ray fluorescence is based on detecting the characteristic X-rays induced in the sample atoms. Qualitative analysis is based on peak positions in the spectrum, quantitative analysis on peak intensities.

In the University of Helsinki the necessary particle beam is produced by a Van de Graaff accelerator. The proton beam energy in the experiments was 2 MeV. The elements from aluminum to bromine by K-X-rays and to element lead by L-X-rays can be determined. The sensitivity for heavier elements is improved if proton energy is increased.

In the PIXE facility of the University of Helsinki (Fig. 1) the samples are irradiated in a vacuum (Raunemaa et al. 1981). In this experiment a proton beam with a diameter of about 1 mm and an average intensity of 5 nA was used. The X-ray counts were stored in a 1024 channel spectrum (Fig. 2), analysis of which was performed by the computer program HHEX (Kaisla 1979, private communication).

Measurement of standard samples in PIXE gives calibration coefficients k for standard elements. In this study the measured coefficients k and a smooth curve fitted to those is presented in Figure 3 as a function of atomic number Z when Z = 15—35.

Use of calibration standards eliminates several errors in the analysis. The standard samples must, however, be prepared in the same way as the material to be analyzed. In this study homogenized pine needle litter was in standard preparation. Five standard series were prepared.

The PIXE method and calibration procedure are more accurately described elsewhere (Raunemaa et al. 1981, Gerlander et al. 1982, Raunemaa et al. 1983).

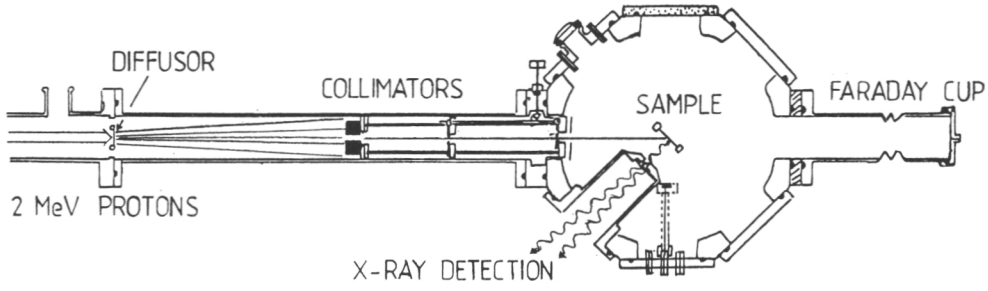


Figure 1. A scheme of the PIXE facility of the University of Helsinki.

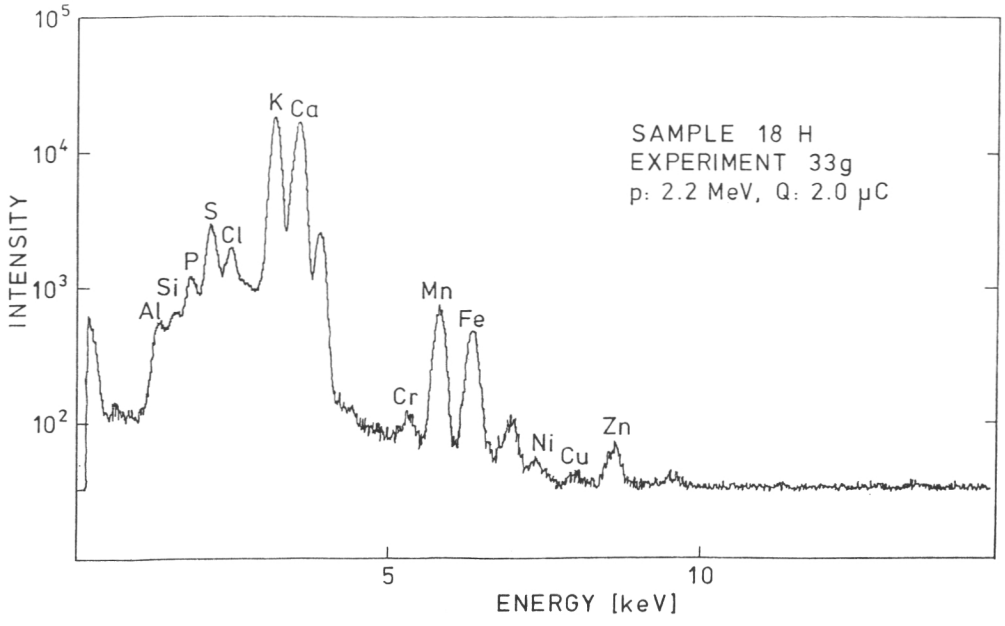


Figure 2. X-ray PIXE spectrum of the sample 18 H.

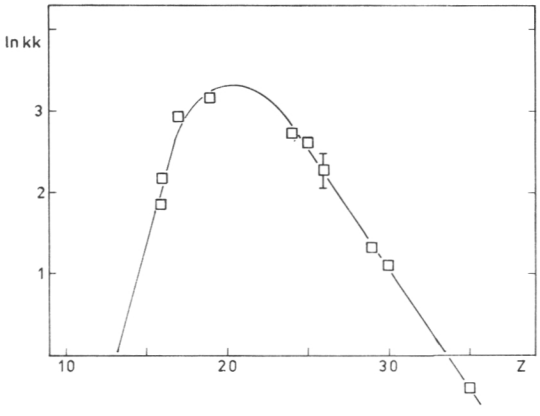


Figure 3. The PIXE calibration curve in the element range Z = 15—35.

Results

The results given by different methods are tabulated in Table 2 and the elements relevant in the comparison illustrated in Figure 4. Because of a limited set of data a wide statistical comparison has been omitted. The differences of the results by PIXE and chemical methods will be in some detail, however, discussed in the following paragraphs.

General

Elements lighter than aluminum were not analyzed by PIXE because of strong absorption of low energy X-rays. This is why boron, nitrogen and magnesium have been analyzed only chemically. The relatively low concentrations of copper in the samples would have required a technical change in the PIXE arrangement, and as this was not kept necessary, copper values have been omitted. The concentrations of sulphur, chlorine and chromium were examined only by PIXE. The number of elements common for both main techniques was eight.

Correlation analysis

The ability of each method in observing different concentrations was tested by calculating the linear correlation of the methods for each element (Figs. 5a-h and 6).

The correlation coefficients are presented in Table 3 and Figure 7. The determinations of silicon, phosphorus, potassium, calcium and manganese agree rather well. Also the mean deviations of concentration values are of the same order of magnitude (see Table 4).

Table 2. Elemental concentrations of the pine needle material obtained by the chemical (k) methods and by the PIXE (p) method. The concentration of nitrogen is given by g/kg, the others in mg/kg.

		Experiment 33 g										
Element		2H	6H	8H	11H	12H	18H	19H	22H	28H	29H	30H
B	p											
	k	2,2	12,0	2,1	2,5	2,0	7,7	1,7	2,3	2,2	3,4	2,1
N	p											
	k	1,26	1,16	1,30	1,15	1,19	1,51	1,23	1,21	1,10	1,37	1,27
Mg	p											
	k	980	1070	780	1150	1040	1110	910	1140	1400	1240	940
Al	p	1200±150	1070±140	1000±130	1400±200	1400±170	1000±110	870±100	800±100	790±110	550±80	850±110
	k	152	74	140	180	153	104	152	134	131	93	102
Si	p	800±100	590±80	760±90	790±100	800±100	580±80	950±110	830=110	1600±200	1150±130	1500±200
	k	350	500	1440	440	500	650	730	1090	1400	450	1540
P	p	780±90	570±70	780±90	970±110	900±100	600±70	860±90	780±90	880±100	600±70	960±110
	k	1210	940	1140	1330	1420	790	1750	1210	1270	960	1300
S	p	840±90	870±90	870±90	930±100	960±100	980±100	910±100	870±90	930±100	890±90	960±100
	k											
Cl	p	230±30	190±20	180±20	210±20	280±30	250±30	200±20	190±20	200±20	220±20	220±20
	k											
K	p	4100±400	3300±300	4000±400	4400±400	5000±500	2700±300	4100±400	3600±400	3700±400	3000±300	4200±400
	k	3640	2850	3130	3410	4540	1910	3350	2900	3310	2350	3220
Ca	p	1200±200	2500±250	2300±230	2500±245	1900±200	2200±200	1510±150	2600±300	2300±200	1800±200	2400±200
	k	2110	2260	2490	2090	1800	1860	1470	2280	2530	1710	2060
Cr	p	36±4	18±3	38±4	17±3	17±3	18±3	27±3	3,4±0,4	45±5	21±3	53±6
	k											
Mn	p	105±11	124±13	94±10	135±14	130±20	200±20	97±11	160±20	125±14	135±14	140±14
	k	106	127	96	130	73	202	95	148	127	150	113
Fe	p	190±20	116±13	260±30	98±11	98±11	200±20	150±20	200±20	230±20	135±15	290±30
	k	34	41	41	39	37	49	48	38	33	49	32
Cu	p	—	—	—	—	—	—	—	—	—	—	—
	k	2,6	3,2	2,3	7,9	2,6	4,2	3,1	2,8	1,8	2,9	2,6
Zn	p	13±7	39±8	12±6	32±8	32±24	18±7	10±7	17±7	33±10	26±7	18±7
	k	202	61	38	85	29	60	89	79	91	41	51

Table 2. Continued

		Experiment 209			Experiment 33 g									Exp. 209
Element		4	8	20	2T	6T	8T	11T	12T	18T	19T	22T	30T	162T
B	p													
	k	20,0	21,0	25,0	2,8	8,2	2,5	2,9	2,3	11,0	2,0	3,8	3,4	3,8
N	p													
	k	1,23	1,20	1,12	1,20	1,25	1,21	1,19	1,24	1,36	1,19	1,21	1,50	1,26
Mg	p													
	k	990	1100	1040	1120	1120	1260	1260	1080	1150	1000	1360	1300	1710
Al	p	970±150	930±115	965±120	995±120	770±95	830±120	860±120	1010±130	760±120	790±110	710±100	900±110	920±120
	k	114	104	63	88	93	123	218	134	145	163	135	216	91
Si	p	750±100	690±90	1340±140	1040±120	1310±140	1010±120	1500±200	1330±150	1130±130	1600±200	1900±200	1900±200	2400±200
	k	620	590	950	1190	1610	830	1320	1330	1750	1640	2380	2110	1500
P	p	640±70	770±90	770±90	720±80	520±60	790±90	850±90	710±80	450±60	650±70	770±90	760±80	930+100
	k	1120	1140	1060	1370	860	1270	1410	1290	800	1290	1420	1150	1410
S	k	880±90	820±90	850±90	840±90	840±90	920±100	790±80	810±80	820±90	760±80	850±90	930±100	940±100
Cl	p	260±30	210±20	250±30	220±20	140±15	200±20	270±30	210±20	160±20	250±30	250±30	260±30	350±40
	k													
K	p	4200±400	4000±400	4100±400	3600±400	2800±400	3900±400	2800±300	4000±400	2500±300	3500±400	3400±300	3600±400	4100±400
	k	3570	3630	3320	3400	2370	4380	2900	4040	2010	3700	3250	3580	4330
Ca	p	1700±200	2100±200	2100±200	1530±160	1560±160	1800±200	1700±200	1700±200	1900±200	1200±120	1700±200	2000±200	2000±200
	k	1730	2250	1960	1590	1520	1770	1900	1770	1290	1420	1620	2080	2340
Cr	p	5,5±1,8	—	11±2	16±2	14±2	38±4	17±2	160±20	7±2	18±3	29±4	11±2	4±2
	k													
Mn	p	440±40	350±40	380±40	120±13	110±11	120±12	125±13	90±10	170±20	105±11	105±11	130±14	140±14
	k	510	450	400	150	130	130	163	96	183	131	124	157	175
Fe	p	70±9	51±8	91±11	145±16	170±20	240±30	94±11	740±80	62±8	125±14	160±20	85±10	64±8
	k	44	47	43	32	34	370	31	35	33	53	54	31	40
Cu	p	—	—	—	—	—	—	—	—	—	—	—	—	—
	k	5,4	5,6	3,6	4,8	3,0	40,0	3,1	2,1	4,2	19,0	11,0	3,8	2,4
Zn	p	26±7	36±8	115±15	19±6	18±6	25±7	12±5	22±6	27±6	34±7	18±5	18±6	21±6
	k	54	51	56	52	63	120	34	127	54	703	38	51	63

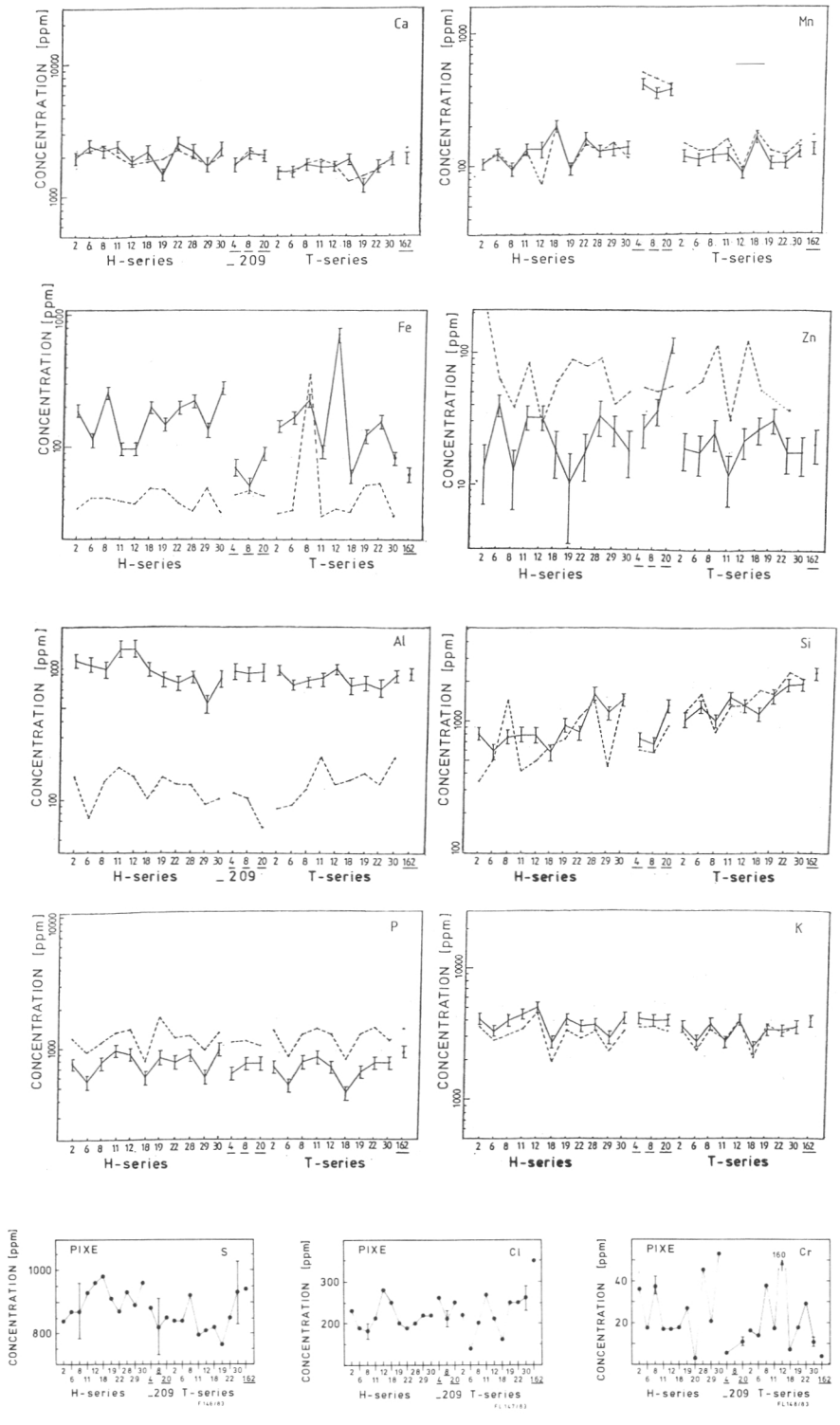


Figure 4. The elemental concentration values given by the chemical methods (dashed line) and PIXE method (solid line) in the needle sample series. H- and T-series originate in the stands 33 g and 209.

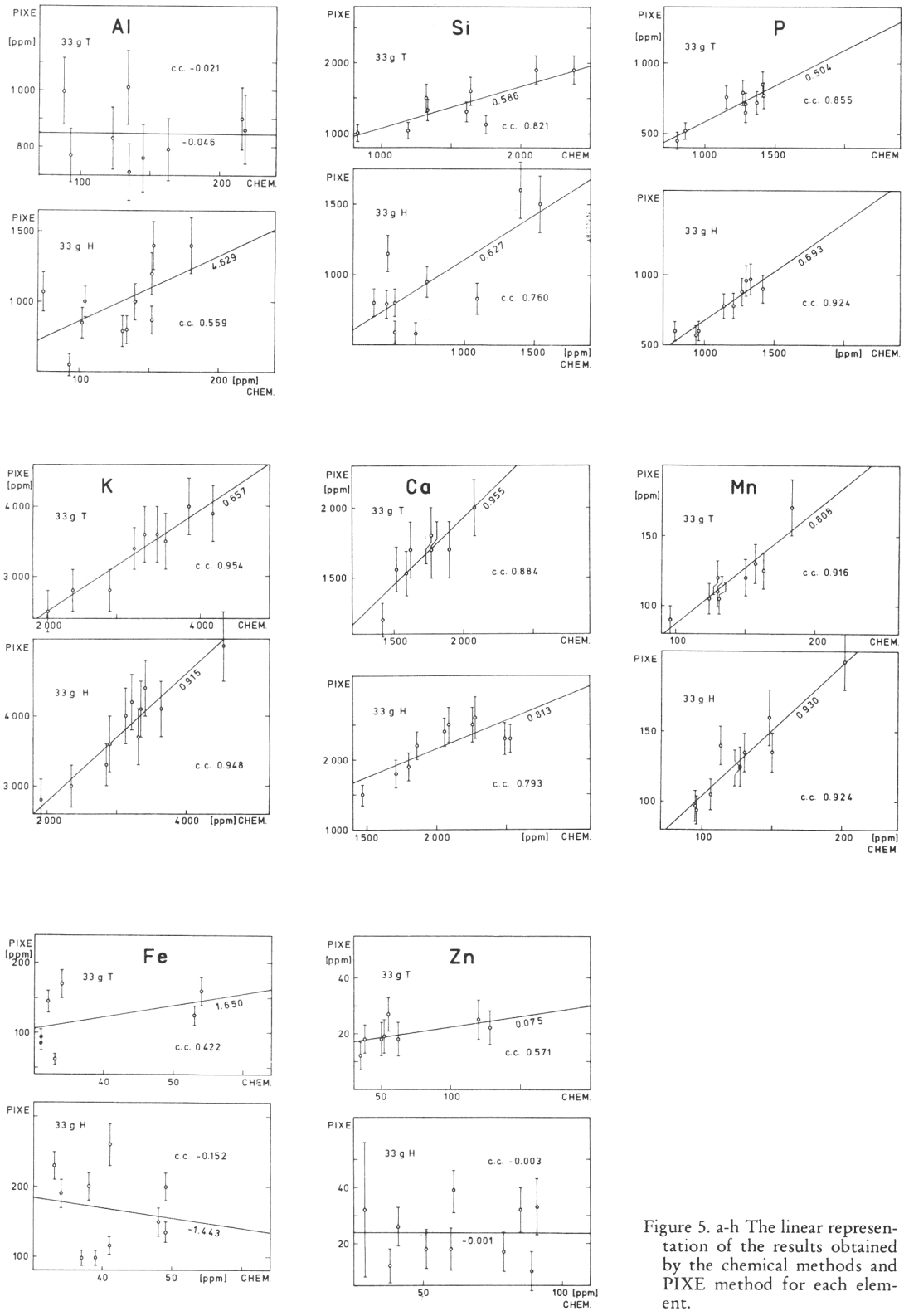


Figure 5. a-h The linear representation of the results obtained by the chemical methods and PIXE method for each element.

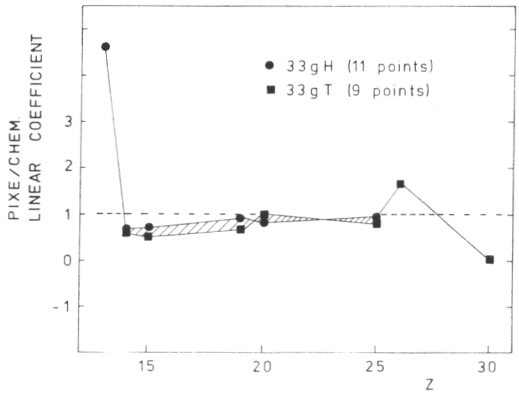


Figure 6. The linear coefficients of the results as a function of the atomic number.

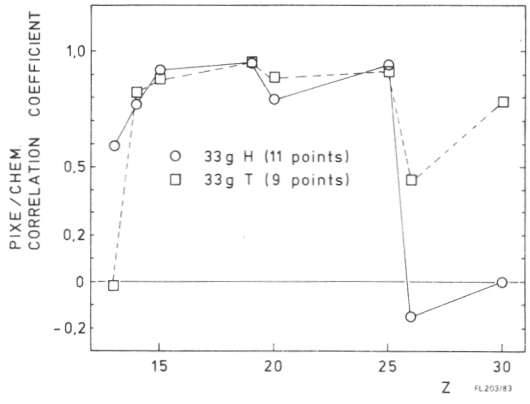


Figure 7. Correlation coefficients of the elemental concentrations by PIXE and chemical methods.

Table 3. The correlation coefficients of elemental concentrations obtained by PIXE and chemical methods.

Element	Experiment 33 g H N = 11	Experiment 209 N = 4	Experiment 33 g T N = 9
Al	0.559*	—0.115	—0.021
Si	0.760**	1.000***	0.821***
P	0.924***	0.804*	0.885***
K	0.948***	—0.057	0.954***
Ca	0.793***	0.689*	0.884***
Mn	0.939***	0.973**	0.916***
Fe	—0.152	—0.388	0.422
Zn	—0.003	—0.126	0.782***

*** corresponds to 1 % confidence level
** corresponds to 5 % confidence level
* corresponds to 10 % confidence level

Table 4. The mean deviations of elemental concentrations observed by PIXE and chemical methods.

Element	PIXE analysis	Chemical analysis
Al	145	35
Si	340	295
P	130	180
K	380	450
Ca	250	260
Mn	36	57
Fe	110	80
Zn	12	45

The determination of aluminum correlates only weakly. The analysis of aluminum by PIXE is, however, problematic because of the strong absorption of X-rays at these energies ($\sim$ 1.5 keV). Comparison with the present PIXE results is therefore not very informative.

The results for zinc are rather inconsistent, especially in growth disturbed trees (experiment 33 g). No correlation at all was obtained for iron. Because sensitivity and error of the PIXE analyses for iron and zinc are rather comparable to those for manganese (closest element to iron), inconsistencies for iron and zinc but not manganese cannot easily be attributed to PIXE determination. Iron and zinc incorrelations are more probable due to unknown random errors in the chemical determinations.

Element concentration values

In PIXE analysis concentration calibration is carried out simultaneously for several detectable elements. Because also of curve fitting (Fig. 3) several error possibilities are eliminated in the smoothing procedure. On the other hand, possible errors will be reflected in all elemental concentrations. In chemical methods element determinations are not in this way related as each element is calibrated independently. Thus methodological errors of different size and direction may appear for single elements.

Accordingly, noticeable differences found for the concentrations of iron and zinc (Table 5) are assumed to be linked with errors in chemical methods. This is supported also by the concentrations (see the iron and zinc data in Fig. 4). The possible errors in the calibration of PIXE would

Table 5. The mean values of elemental concentrations observed by PIXE and chemical methods.

Element	Experiment 33 g H-series			Experiment 209			Experiment 33 g T-series		
	PIXE	Chem.	PIXE/ chem. (%)	PIXE	Chem.	PIXE/ chem. (%)	PIXE	Chem.	PIXE/ chem. (%)
Al	940±80	130±10	723	955	94	1016	850	140	607
Si	940	825	114	925	720	128	1510	1570	96
P	785	1210	65	725	1110	68	715	1230	58
K	3820	3150	121	4070	3510	116	3400	3290	103
Ca	2160	2060	105	1980	1980	100	1690	1730	98
Mn	130	125	104	395	455	87	120	145	83
Fe	180	40	450	71	45	158	190	78	244
Zn	23	75	31	59	54	109	21	63	33

appear in almost equal magnitudes in all samples.

The large difference in aluminum concentrations between different analysis methods is rather apparent. The concentration levels of silicon, potassium, calcium and manganese agree well when measured by different methods. Especially calcium correlates well. The results for phosphorus measured by PIXE are on average 65 % of those measured by chemical method although relative determinations correlate well (Fig. 4 and Table 5). A detailed analysis of the phosphorus X-ray data gives an estimate for a possible PIXE error. The background caused by bremsstrahlung and interference by other X-ray peaks may result in a systematic error of the X-ray intensity of phosphorus. This background error would lead too a small concentration of phosphorus by PIXE. Correlation between the samples would not be affected.

The iron concentrations given by PIXE are on average four times those obtained chemically, and the zinc concentrations only one third, respectively. This opposite fluctuation between close elements is not plausible if, for a moment, only the PIXE method is concerned. Analytical errors in chemical analyses have even been suggested.

Characteristics of growth disturbed and sound tree needle samples

The results obtained by PIXE (and by chemical methods) can be applied for a limited disturbance characterization of sample stands. Fertilization has been effected in most of the study trees (c.f. Table 1), only samples numbered 6, 18, and 29 were left unfertilized in the experiment 33 g. The effect of fertilization can be cleared up by comparing the different element concentrations. It is obvious that the elements aluminum, phosphorus, potassium and less certainly also silicon appear with higher concentrations in the needles of fertilized than in unfertilized sample trees. In the experiment 209 the wet ash fertilization seems to increase the silicon and phosphorus concentration but to decrease the zinc and manganese level.

When the growth disturbed trees are compared to the sound trees, the average elemental concentration in growth disturbed needle samples is apparently higher for calcium and iron with probable increase also for aluminum, phosphorus and potassium, and very clearly lower for silicon. The other elements in PIXE analysis did not show statistically significant differences. The average concentration values are compared in Table 6. In chemical analyses boron and

Table 6. The element concentration ratio of the needles in growth disturbed and sound trees in the experiment 33 g.

Element	Growth disturbance/sound		
	All	PIXE	Chem.
B	—	—	0.85
N	—	—	0.99
Mg	—	—	0.90
Al	1.02	1.17	0.87
Si	0.57	0.68	0.46
P	1.04	1.13	0.95
S	—	1.08	—
Cl	—	0.99	—
K	1.04	1.13	0.95
Ca	1.23	1.33	1.13
Cr	—	0.78	—
Mn	0.97	1.10	0.84
Fe	1.19	1.40	0.98
Cu	—	—	0.51
Zn	1.14	1.06	1.22

especially copper had low values in growth disturbed tree needles. The observed differences may be usable in growth disturbance diagnosis.

Conclusions

Due to comparison the elements silicon, potassium, calcium and manganese are determined with an acceptable precision and concentration by PIXE and by chemical methods. Also phosphorus can be counted to this cathegory, when the level error is taken into account.

The analysis of aluminum in these experiments by PIXE cannot be compared with the chemical one. The results for iron and zinc given by the chemical methods deviate noticeably and to opposite directions from those given by PIXE, and are both assumed to be in error.

The advantages of PIXE when compared to the chemical methods are its ability to analyze all elements simultaneously, increased speed of analysis and possibility for cross-checking of the results. PIXE is also nondestructive. Disadvantages of PIXE include unable determination of light elements and need for massive equipments.

The use of PIXE for diagnostics in growth disturbance trees can be proposed.

Literature

GERLANDER, M., RAUNEMAA, T., HAUTOJÄRVI, A. & SAMELA, J. 1981. Thick sample analysis with PIXE. Report series in Physics, HU-P-215, University of Helsinki.

JOHANSSON, S.A.E. (Ed.) 1981. Proton induced X-ray Emission Proceedings of Second International Conference on Particle X-ray Emission, Nuclear Instruments and Methods 181.

KOLARI, K.K. 1979. Hivenravinteiden puute metsäpuilla ja männyn kasvuhäiriöilmiö Suomessa. Kirjallisuuskatsaus. Abstract: Micro-nutrient deficiency in forest trees and dieback of Scots pine in Finland. A review. Folia For. 389.

RAUNEMAA, T., VAITTINEN, M., RÄISÄNEN, J., TUOMI, T. & GERLANDER, M. 1981. Sample changing facility with Electronic control in PIXE analysis. Nuclear Instruments and methods 181: 43—48.

— , HAUTOJÄRVI, A., SAMELA, J., ERKINJUNTTI, R., HARI, P. & KELLOMÄKI, S. 1983. On seasonal variation in the nutrient content of needle litter from scots pine. (To be published in Can.J.For.Res. 1983).

SILFVERBERG, K. 1980. Kuusen kasvuhäiriö ja hivenravinteet: Abstract: Micronutritional growth disorder in Norway spruce. Folia For. 432.

SIPPOLA, J. & ERVIÖ, R. 1977. Determination of boron in soils and plants by the Atsomethine-H. Finn. Chem. Lett. 1977 (4—5): 138—140.

VEIJALAINEN, H. 1977. Use of needle analysis for diagnosing micronutrient deficiences of Scots pine on drained peatlands. Commun.Inst.For.Fenn. 92(4).

WILLIS, R.D., WALTER, R.L., SHAW Js., R.W. & GUTKNECHT, W.F. 1977. Nuclear instruments and methods 142: 67—77.

Total of 9 references

TRANSPORT MODEL OF NUTRIENTS

Juha Samela and Taisto Raunemaa

Methodological aspects of employing mathematical modelling in the research of nutrient balance in forest trees is briefly discussed. As examples, two experimentally verified models are introduced.

Introduction

In forest trees an unbalance in nutrient composition often indicates disturbances in photosynthesis and in growth even though no visible effects are shown. Traditionally statistical methods are employed to find out and study these correlations between nutrient balance and growth disturbances or other visible effects in forest trees. Many exellent papers exist in this field of research. However, no unified theory is available.

It is most probable that progress can be made in research of nutrient balance by employing also other mathematical modelling techniques than regression analysis. The authors have employed state variable models (Hari 1979) to study if certain biophysical arguments can be used to explain measured variations in nutrient composition of biomass. The models are based on the assumption that environment affect the functioning of a tree both strictly and through the complex self-regulation. Self-regulation is not modelled by starting at the level of biochemical reactions, because it would lead to too cumbersome models to handle. Instead, self-regulation is described by a suitable mathematical function.

As an example, two experimentally verified models are discussed. Full model structure with regulating function is not used in these examples because of limited experimental material available in model verification.

The transport model for Scots pine needles

In an investigation of long-term effects of SO_2 on forests (Raunemaa et al. 1982a) the elemental composition of aged Scots pine (*Pinus silvestris* L.) needles from different years were analyzed. In order to understand the great yearly variations of the nutrient levels in these time series an internal transport model was constructed. With only minor alternations, this model can be applied to other biomass systems.

The model has been formulated in terms of the linear state variable method (e.g. Hari et al. 1981). As state variables, we have taken the amounts of the elements m_i (i=1,...,n) in an idealized needle, i.e. a metabolically still active, second or third year needle. The different elements are assumed to enter the needle during the transpiration process. The water flow W, in addition, rinses the elements towards the surface of the needle. As material outflow, we take phloem flow, for hydrocarbons and other compounds produced in the needle. Furthermore, the changes in the amounts of elements in the needle are assumed directly comparable with the growth intensity I of the branch closest to the needle in question. Thus, the intensities of water flow W and growth rate I become input variables, which can be calculated using suitable transpiration and growth models, respectively. In these models variables like day temperature or light intensity can be used to describe environment. The output of transpiration and growth models can be approximated by piecewise linear functions if the environmental factors are not measured.

For a needle, a difference equation is now valid

$$(1) \qquad m_i(k+1) = m_i(k) + a_iW(k) - b_iI(k)\ ,\ k=1,...,365$$

Where a_i and b_i are parameters, i denotes elements and k denotes days.

During the senescence period, which lasts about 10 days, some nutrients leave the needle, while the amounts of other increase (Mälkönen 1974). It would seem to be true that the intensity of the processes which lead to senescence (but the details of which are not precisely known) varies through the seasons, with maximum of minimum intensity (dependeng on an element) occuring at the beginning of autumn; i.e. when most old needles fall.

For a senescing needle, the equation

$$(2) \qquad m_i(k) = m_i(k-1) - c_iS(k) \qquad ,\ k=1,...,10$$

is valid. The strength function S(k) gives the relative intensity of senescence. It can be approximated by piecewise linear function. c_i is a parameter.

The computer simulation based on equations (1) and (2) and the piecewise linear approximations of functions W, I and S have been performed for the elements P, S, Cl, K, Ca and Mn. The results of simulations are compared with the corresponding experimental concentrations for different years (Fig. 1). The comparison shows the observed elemental variations can be explained to be due to three processes: transpiration, phloem flow and senescence. The simulation without senescence gives not so good results. The model and the experimental methods are more detailedly discussed in Raunemaa et al. (1983).

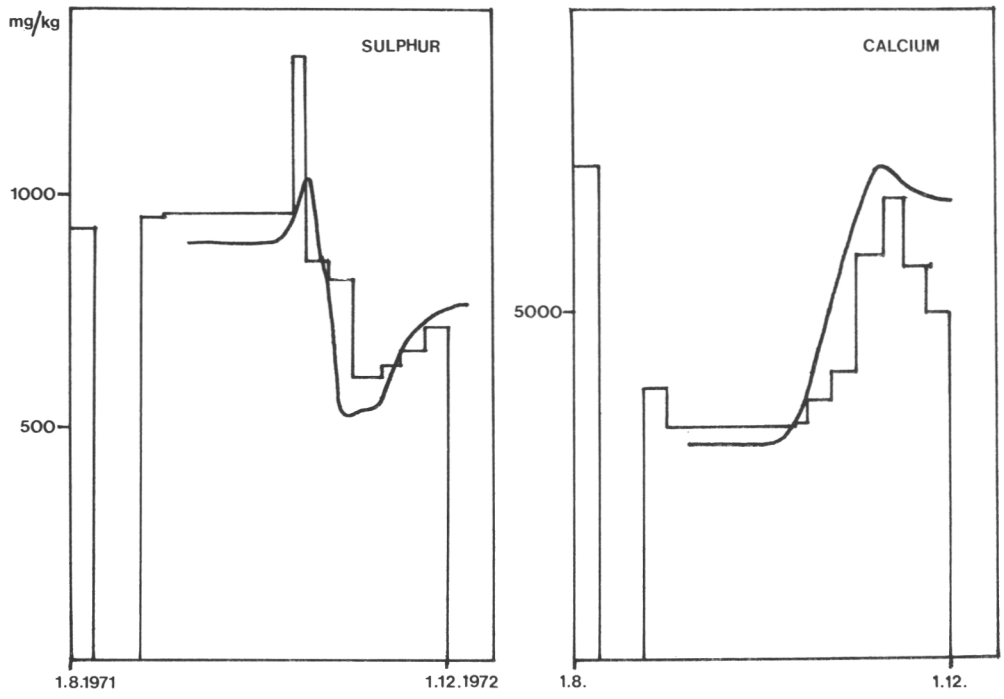


Figure 1. The concentrations of sulphur and calcium in Scots pine needle litter for a forest in southern Finland during the period August 1971 trough December 1972. The model simulation is illustrated by continous lines and the experimental values by columns, the widths of which represent the collection periods.

The model for willow

The model based on the same arguments, namely that the amount of an element in green biomass depends on transpiration, phloem flow and intensity of senescence, is under development for willow (*Salix aquatica*) leaves. In the first version of the model the transpiration rate and the intensity of senescence are assumed to be strictly comparable with day temperature. Because willow has relative simple structure and growth behaviour, no seasonal control is assumed in the model.

The equation of state in autumn after the growth has ceased is

$$(3) \quad m_i(k+1) = m_i(k) + a_i W(k) - c_i S(k) \qquad , i=1,...,n$$

where a_i and c_i are parameters and k denotes days. The transpiration rate W is assumed to depend linearly on day temperature T

$$(4) \quad W(k) = p_1 T(k).$$

The intensity of senescence is zero at warm days, when day temperature T is below a critical temperature T_c. Otherwise it also depends linearly on day temperature

$$(5) \quad S(k) = \begin{cases} p_2(T_c - T(k)) & , T(k) < T_c \\ 0 & , T(k) \geq T_c \end{cases} .$$

The comparison to experimental data is shown in Figure 2. The correlation (0.84) between experimental and simulated values of potassium concentration is only slightly better than correlation between experimental data and the measured day temperatures (0.81). The result indicates that the model has not enough structure to show if the basic arguments are valid. The dependence of potassium concentration on cumulative day temperature is clearly demonstrated. Further evaluation of the model have not been possible due to lack of experimental data (Raunemaa et al. 1982b).

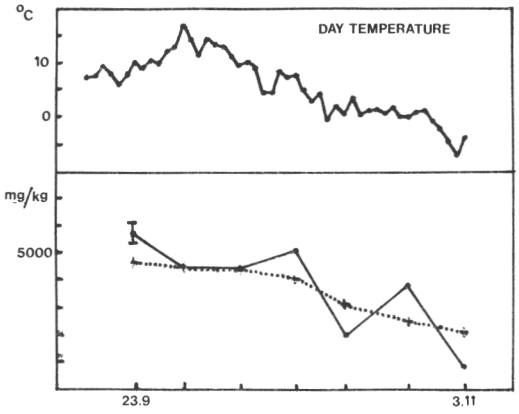


Figure 2. The average concentration of potassium in willow leaves (Salix aquatica) from Piipsanneva in autumn 1981. The result of simulation is illustrated by the broken line.

Conclusions

In the research of nutrient balance and related visible effects the dynamical modelling can be employed to organize existing experimental data and competing theoretical assumptions. The two models discussed here demonstrate a practical course of modelling. The main features of this practice can be summarized as follows:

1. There must be available enough experimental material to evaluate the model. Often the complexity of the model is limited because there is not enough experimental data available.
2. The basic arguments of the model must be clearly specified before the mathematical equations are constructed.
3. The mathematical structure of the model should be simple. Parameters which do not affect significantly to the model output can be cancelled.
4. Computer simulations based on the equations of the model can be used to study the model and develop it.
5. During the construction of a model new experiments are often suggested.

An unified mathematical model for dynamical nutrient composition of plant biomass is not probable in near future. Models for distinct parts of plants are first to be constructed. However, these minor models can be of great value in practical forestry and agriculture sciences.

Literature

HARI, P., MÄKELÄ, A. & SIEVÄNEN, R. 1981. Systems concepts in theoretical plant ecology. Helsinki University of Technology, Systems Theory Laboratory. Report Series B 60.

MÄLKÖNEN, E. 1974. Annual primary production and nutrient cycle in some Scots pine stands. Commun.Inst.For.Fenn. 84(5).

RAUNEMAA, T., HAUTOJÄRVI, A., KAISLA, K., GERLANDER, M., ERKINJUNTTI, R., TUOMI, T., HARI, P., KELLOMÄKI, S. & KATAINEN, H-S. 1982 a. The effects on forest of air pollution from energy production: Application of the PIXE method to elemental analysis of pine needles from the years 1959—1979. Canad. J. For.Res. 12(2).

RAUNEMAA, T., SAMELA, J. & KANTELE, O. 1982b. Ydinfysikaalisten menetelmien soveltaminen kotimaisen energiaraaka-aineiden ominaisuuksien ja energiamuunnon tutkimiseen. Univ. of Helsinki, Institute of Physics. Int. report (in finnish only).

— , HAUTOJÄRVI, A., SAMELA, J., ERKINJUNTTI, R., HARI, P. & KELLOMÄKI, S. 1983. On seasonal variation in the nutrient content of needle litter from Scots pine. (to be published in Canadian Journal of Forest Research).

Total of 5 references

SESSION 3.

PATHOLOGICAL SURVEYS OF GROWTH DISTURBANCES

FUNGAL DISEASES ASSOCIATED WITH NUTRITIONAL GROWTH DISTURBANCES OF SCOTS PINE

Timo Kurkela

Introduction

The effect of mineral nutrition on the susceptibility of forest trees to biotic pathogens is still relatively unknown. Most studies of the relationship between nutrients and diseases of forest trees describe the effect of macronutrients. This is the case in several articles, e.g. Foster (1968), Hesterberg and Jurgensen (1972), and Dimitri (1977). In a very few cases, the effects of micronutrients have also been recorded, e.g. Iyer et al. (1971).

In Finland, some diseases have been found in association, or have appeared in the same sites, with nutritional growth disturbances, which is the topic of this seminar. The major part of the observations have been made in the forest fertilization experiments at Kivisuo (see e.g. Huikari and Paarlahti (1966) for the description of these experiments). Snow blight (*Phacidium infestans* Karst.), gremmeniella canker and die-back (*Gremmeniella abietina* (Lagerb.) Morelet), and grey needle cast (*Lophodermella sulcigena* (Rostr.) v. Höhn.) are the biotic diseases which have been studied in connection with mineral nutrition or fertilization of Scots pine (*Pinus sylvestris* L.) stands. This paper reviews these cases, most of which have been reported earlier, and discusses the possible connection of disease with nutrition at growth disturbance.

Relationship between mineral nutrition and diseases

Snow blight

Snow blight is caused by the fungus *Phacidium infestans* which is spread by airborne ascospores among pine foliage. Infection occurs only in needles under the snow cover. Mycelial fans growing from previously infected needles systematically kill all snow covered foliage they are able to reach. The disease is most serious in pine reforestations and nurseries in eastern and northern Finland, that is, areas with long winters and deep snow cover.

The first survey of snow blight at Kivisuo was made in the spring of 1964, when pines had grown five seasons in Experiment I. Potassium (K) and phosphorus (P) interacted strongly in their effect on snow blight. Disease incidence increased with potassium fertilization without phosphorus, and also with phosporus fertilization without potassium. Disease incidence was lowest on the plots without potassium and phosphorus treatment; almost the same reasonable level of the disease, and in addition good growth, were obtained with balanced PK-fertilization (Kurkela 1965, 1975). According to Keller (1979), imbalanced mineral nutrition, including N, P, and K, increases respiration and thus energy loss, which in sequence decreases resistance to snow blight fungi in the foliage.

In the survey of 1964, a die-back related to a high amount of potassium (see Kurkela, p. 10 in this Proceedings) and winter drying of foliage on the plots lacking phosphorus treatment, were observed. Serious winter drought also resulted in die-back (Kurkela 1979). Neither of these die-back phenomena was correlated with snow blight. Since abiotic nutritional growth disturbance does not usually appear until 8—10 years after NPK-fertilization (cf. Veijalainen 1975, Kolari 1979) when pines are tall enough to avoid snow blight, the association of snow blight and growth disturbance can hardly exist.

Gremmeniella canker and die-back

The fungus *Gremmeniella abietina* was already found to be associated with the 1964 die-back at Kivisuo. The fungus has commonly been observed occupying and forming conidia on the dead shoots of pines with an appearance of nutritional growth disturbance (Kurkela 1981). However, growth disturbance in Scots pine can be divided into several different phenomena all of which may finally result in a shrubby form or the death of a tree.



Figure 1. Growth disturbance in a Scots pine. The tree has not been able to form new leader shoot in the last growing season. Height increment has already declined during the previous season. The buds are seriously deformed.

G. abietina is not, or is very seldom, associated with growth disturbance in which the first symptoms are deformation of vegetative buds and decrease in the length of leader shoots from season to season (Fig. 1). Sometimes die-back also occurs without previous decrease of growth and buds are killed, badly deformed, or even undeveloped (Fig. 2, see also Fig. 1 p. 11 in this Proceedings). Such shoots are often hypertrophied at the apex or along the whole length. This phenomenon is also common on *Pinus*



Figure 2. Hypertrophied leader shoots with stunted needles and deformed buds, which usually results in die-back.



Figure 3. A Scots pine killed by *Gremmeniella abietina*. The four uppermost internodes were killed first and then, after two years, the whole tree.

cembra L. and *P. peuce* Griseb used as ornamental trees. Shoot hypertrophy seems to develop at the same time as bud deformations. In some cases, die-back in ornamental trees has been controlled with the application of a commercial NPK-fertilizer containing a selected mixture of micronutrients. Although dying, hypertrophied shoots are obviously good growing sites for *G. abietina*, and are indeed often colonized by the fungus, the fungus itself can hardly be more than a secondary cause in the killing of buds and shoots.

Usually, *G. abietina* is associated as a primary causal agent in a growth disturbance which appears as acute die-back without previous decrease of internodal growth (Fig. 3). In the field of plant pathology, this disease is recognized as gremmeniella die-back (see Kurkela 1981). Pine is normally resistant to the disease, but it may become susceptible when it is predisposed by unfavorable climatic factors, e.g. cold and moist growing season (Donaubauer 1972). Together with climatic factors, imbalanced mineral nutrition (probably boron deficiency) may also act as a predisposing factor. Many observations in the field support this opinion, but concrete evidence is still lacking.

G. abietina can be isolated from dying shoots when the first symptom, a slight greyish green or brown colour, appears in the foliage in the spring. Infection occurs in the previous growing season in predisposed trees. Since boron obviously increases the frost (or winter) hardiness of trees, e.g. that of *Picea abies* Karst. (Braekke 1979), it is not surprising that boron may also determine the resistance of pines to *G. abietina*. Inoculation tests (e.g. Kurkela and Norokorpi 1979) have shown that mycelia of *G. abietina*

extend in living pine tissue mainly during the dormant period of pine when there exists no active defence reaction against fungal invasion in the tissue. The formation of defence barriers, nonimpervious tissue and necrophylactic periderm, can also be inhibited during a cold period in growing season (see Mullick 1977), which makes fungal invasion possible. It will be interesting to study the role of boron in defence reactions.

Grey Needle Cast

The third disease, grey needle cast caused by *Lophodermella sulcigena*, also has a clear connection with the mineral nutrition of pines. On dry sandy sites only a few pines are susceptible, others seem to be immune to the disease. Jalkanen (1982) showed that a great part of the resistance in pines is genetically determined. In reforestations on fresh fertile sites, pine is usually susceptible (Krutov 1979) and sometimes totally loses its inherited resistance.

Grey needle cast has never been found in correlation with the symptoms of nutritional growth disturbance. When the disease occurs on the same site with growth disturbance, it appears on both trees with and without symptoms of disturbance (Kurkela and Jalkanen 1981).

In Experiment I at Kivisuo, potassium had a significant effect on the disease incidence, which was lowest with application of intermediate amounts of potassium. In another case, nutrient analysis carried out on the needles revealed that the level of nitrogen, phosphorus, and potassium was clearly higher in the diseased stand growing on a moist site than in the completely healthy stand on a dry site. The amount of manganese was substantially less, and the amount of zinc and boron also slightly less, in the diseased stand. However, within any particular site, variation in the amount of a single mineral in the needles was only slightly correlated with disease incidence. It appears that the relationship between the macronutrients (N, P, and K) and micronutrients, together with other soil factors on moist fertile sites, are able to break down the inherited resistance against grey needle cast which is effective on dry sites. Obviously, the same physiological factors may be involved in predisposing pines to *L. sulcigena* and in the manifestation of abiotic growth disturbance symptoms, but the mechanisms by which they act seem to be totally different in these two phenomena.

References

BRAEKKE, F. H. 1979. Boron deficiency in forest plantations on peatland in Norway. Medd. Nor. inst. skogforsk. 35: 213—236.

DIMITRI, L. 1977. Influence of nutrition and fertilizer use on the resistance of forest plants to fungus diseases. In "Fertilizer Use and Plant Health", Proc. 12th Colloq. Int. Potash Inst., Izmir, Turkey 1976, pp. 167—176.

DONAUBAUER, E. 1972. Environmental factors influencing outbreak of Scleroderris lagerbergii Gremmen. Eur. J. For. Path. 2: 21—25.

FOSTER, A. A. 1968. Damage to forest by fungi and insects as affected by fertilizers. In "Forest Fertilization — Theory and Practice", Papers presented at Symp. For. Fertiliz. 1967, Gainesville, Flo. (Tennesse Vall. Auth.), pp. 42—46.

HESTERBERG, G. A. & JURGENSEN, M. F. 1972. The relation of forest fertilization to disease incidence. For. Chron. 48: 92—96.

HUIKARI, O. & PAARLAHTI, K. 1966. Kivisuon metsänlannoituskokeet, kenttäopas. Helsinki.

IYER, J. G., SCHULTE, E. E., & RANDALL, G. W. 1971. Relationship between foliar composition of red-pine and jack-pine seedlings and vulnerability to Lophodermium needle-cast disease. Plant and Soil 35: 213—216.

JALKANEN, R. 1982. Lophodermella sulcigena in clones and progenies of Scots pine in Finland. In: Heybroek, H. M., Stephan, B. R., & Weissenberg, K. von (Eds.) "Resistance to Diseases and Pests in Forest Trees". Proc. 3rd Int. Workshop on the Genetics of host-parasite interactions in forestry, Wageningen, the Netherlands, 14—21 September 1980, pp. 441—447.

KELLER, T. 1970. Wuchsleistung, Gaswechsel, Uberlebensprozente und Schneeschimmelpilzbefall gedüngter Ballenpflazen an der oberen Waldgrenze. Mitt. Schweiz. Anst. forstl. Versuchsw. 46.1: 1—32.

KOLARI, K. K. 1979. Hivenravinteiden puute metsäpuilla ja männyn kasvuhäiriöilmiö Suomessa — kirjallisuuskatsaus. (Micronutrient deficiency in forest trees and dieback of Scots pine in Finland — a review.) Folia For. 389: 1—37.

KRUTOV. V. 1979. O parasitnoj mikoflore iskusstvennyh fitocenozov sosny na byrubkah Karel'skoj ASSR i Murmanskoj oblasti. (On the parasitic mycoflora of artificial pine phytocoenoses in the Karelian A.S.S.R. and Murmansk region). Mikologija i Fitopatologija 13: 342—349.

KURKELA, T. 1965. Männyn lumikaristetaudin ja lannoituksen suhteesta Kivisuon metsänlannoitusalueella. (On the relationship between the snow blight (*Phacidium infestans* Karst.) and fertilization on Scotch pine seedlings). Folia For. 14: 1—8.

— 1975. Incidence of snow blight on Scots pine as affected by fertilization and some environmental factors. Commun. Inst. For. Fenn. 85.2: 1—35.
— 1979. Effect of fertilization on winter drying of Scots pine. Proc. IUFRO Seminar "Mountain Forests and Avalanches", Davos, 1978, pp. 139—143.
— 1981. Versosyöpä (*Gremmeniella abietina*) riukuasteen männiköissä. (Canker and die-back of Scots pine at precommercial stage caused by *Gremmeniella abietina*). Folia For. 485: 1—12.
— & JALKANEN, R. 1981. Deformations and susceptibility of pine needles to *Lophodermella sulcigena* resulting from imbalanced nutrient status. "Current research on conifer needle diseases", Proc. IUFRO W. P. on Needle Diseases, Sarajevo, 1980, ed. Millar, C. S., pp. 37—41
— & NOROKORPI, Y. 1979. Pathogenicity of *Scleroderris lagerbergii, Lachnellula pini,* and *L. flavovirens* and their cankers on Scots pine. Commun. Inst. For. Fenn. 97.1: 1—16.
MULLICK, D. B. 1977. The non-specific nature of defence in bark and wood during wounding, insect and pathogen attack. "The structure, biosynthesis and degradation of wood", eds. Loewus, F. A. & Runeckles, V.C., Recent Advances in Phytochemistry 11: 395—442.
VEIJALAINEN, H. 1975. Kasvuhäiriöistä ja niiden syistä metsäojitusalueilla. (Dieback and fertilization on drained peatlands). Suo 26(5): 87—92.

Total of 19 references

VIRUSES IN CONIFER NEEDLES IN FINLAND: DESCRIPTION OF VISIBLE SYMPTOMS AND ULTRASTRUCTURAL ABERRATIONS OF MESOPHYLL TISSUE

Sirkka Soikkeli

The needles of *Picea abies* (L.) Karst. and *Pinus sylvestris* L. were collected from several fertilized forests (experiment areas of the Finnish Forest Research Institute) and from areas polluted slightly by air pollutants. All of the trees are over 30 years old. Part of them show growth disturbances, e.g., stunted needles, asymmetric growth and top dying. These symptoms are usually connected to nutrient imbalance. In this material they may be partly due to virus diseases, too. Many of the studied trees have also yellow mosaic areas in needles which is very likely a symptom of viruses. For cytopathological studies mainly green needles were taken from both disturbed and healthy looking trees. The virotic symptoms in the fine structure of needles were numerous and partly similar in both conifers. The cytoplasmic signs of disease were different kinds of membraneous structures, cylindrical inclusions and aggregations of electron dense vesiculated material. The cells also showed three kinds of chloroplast aberrations: the type with fused electrondense grana lamellae and two types having no grana and differing from each other in organization of the stroma lamellae. The mitochondria had amorphous or granular material in the matrix. The nucleus showed aberrations, too. but only in few cases.

Introduction

One of the first opinions that disease in conifers might be caused by viruses was given by Blattný (1939, 1948). Later virus diseases have been recorded in many conifers, e.g., in *Picea abies* (Černy et al. 1977), in *Pinus sylvestris* (Yarwood 1959), and in *Picea sitchensis* (Biddle and Tinsley 1968). The visible symptoms often mentioned with virus-diseases are the yellow chlorosis in needles, stunted needles, asymmetrical growth of the twigs, and dying of the top.

Rod-shaped particles assumed to be

viruses have been described electron microscopically from the exudates of the diseased branches (Cech et al. 1961, Biddle and Tinsley 1968). Černy et al. (1977) have described isometric particles from needles of *Picea abies*. The occurrence of viruses has been mentioned also in roots of conifers (Yarwood 1959, Harrison 1964). *Sacchiphantes abietis* L. (Čech et al. 1961), nematodes (Harrison 1964, McElroy et al. 1977), and *Armillariella mellea* (Černy et al. 1977) have been reported as possible vectors.

This study is part of a project dealing with diagnosticity of the cytopathological changes of plants in respect of harmful environmental agents, especially air pollutants. The aim of this study is to give for the first time a cytopathological description of the occurrence of viruses in Norway spruce and Scots pine needles.

Materials and methods

The needles of *Picea abies* (L.) Karst. and *Pinus sylvestris* L. were taken from several forests having both visibly healthy and diseased trees. The study areas are fertilized forests (experiment areas of the Finnish Forest Research Institute) and unfertilized forests with low level of air pollutants. Usually the forests were monocultures, spruce or pine solely. The reference material was taken from unfertilized plots of experiment areas and from naturally growing mature unpolluted forests. The study includes 125 spruce trees and 85 pine trees, which all are over 30 years old.

For the cytopathological studies the second-years green needles were taken from the highest branches of the trees. The sampling time was during March and April in 1980. The needles were cut immediately after the branch was taken down and put into a fixative solution of 2 % glutaraldehyde in phosphate buffer (0.1 M, pH = 7.0). The samples for microscopic observations were taken about 2 mm from the tip of the needle. The needles were always sectioned in a drop of 2 % glutaraldehyde on the day of the sampling. The fixation procedures, staining, and examination of the mesophyll tissue were the same as described by Soikkeli (1978, 1980).

Results

Visible symptoms

In the fertilized forests the visible damages of mature pines often occurred as top-dying and sometimes as stunted needles. The spruces had bush-like growth especially in the uppermost parts of the trees. Neither top-dying nor bushy growth were common in the areas polluted slightly by air pollutants. The yellow mosaic areas in needles of both conifer species were usual in both fertilized and air polluted areas. Yellow mosaic could be seen also in naturally growing unpolluted mature trees but not as frequently as in changed environments.

Ultrastructural aberrations

The ultrastructural abnormalities in mesophyll tissue of the green needles were found in every visibly damaged tree both in fertilized and slightly air polluted areas. The trees in reference plots of fertilized experiment areas had both needles with normal ultrastructure (Fig. 1) and needles which had part or all of the abnormalities described here. The reference material taken from



Figure 1. Normal winter structure of pine needle mesophyll cell. The intact chloroplasts (C) and mitochondria (M) can be seen. Cell wall (Cw), normal cytoplasm (Cy), and part of the central vacuole (V) are present. The fine structure of spruce needle mesophyll is greatly similar. Bar = 500 nm.

naturally growing unpolluted trees had none of these abnormalities.

Cytoplasmic symptoms

Mesophyll cells of spruce needle had cylindrical inclusions which consisted of laminated aggregates, tubes and scrolls (Fig. 2). The structures were freely in the cytoplasm. When the bodies were numerous the aggregations of electron-dense vesiculated material were seen. They were often grouped with lipid droplets (Fig. 2) or near or in the chloroplasts (Fig. 7a). In some cases the pine needle mesophyll cells had electron-dense, rather thick flexuous pinwheel-like structures (Fig. 3).

The thin, heavily curled filament aggregation sometimes with black indistinct globules inside could be distinguished in the cytoplasm as usually in both conifers (Fig. 4). Multilayered membranes (Fig. 4) and abnormal paramural bodies (Fig. 5) were seen near or in contact with the plasmalemma or tonoplast. These inclusions were more common in pine than in spruce.

In some cases the cytoplasm of the pine needle cells had electron opaque areas. The area had big paramural bodies with osmiophilic material but none normal cell organelles. It was not limited with membranes from the normal cytoplasm. In this area a lot of rod-like flexuous particles were distinguished (Fig. 6).

Symptoms in chloroplasts

The heavily curled filament aggregations similar to those seen in the cytoplasm were seen also in chloroplasts as a very first sign of the symptom complex (see Fig. 4). The aggregations were often surrounded by electron opaque areas.

The chloroplasts had three kinds of structural aberrations. The first type had grana in which the lamellae were fused together being more electron-dense than usually (Fig. 7a). The stroma lamellae were undulating or making one or several circles. In some cases the stroma was vesiculated in the peripheral areas of the plastid and the thylakoids might be swollen.

The second aberrated plastid type had pellucid stroma and heavily curved lamellae without any grana (Fig. 7a). The chloroplast seemed to disappear gradually leaving behind only plastoglobuli and in the place of thylakoids undulated or circled bands, which resembled hairy string of pearls (Fig. 7b). These two types of aberrations were seen alone or together in the same cells as laminated aggregates, tubes and scrolls in spruce needle. They were seen also in pine needle cells together with pinwheel-like structures.

The third changed plastid type had undulating thylakoids without any grana (Fig. 8). In the end it was possible to see the place of the disappeared chloroplast only with the help of plastoglobuli. This type was common in pine needle cells with paramural bodies and multilayered membranes.

Other symptoms

The cells with inclusion bodies in the cytoplasm and plastid aberrations had abnormalities also in mitochondria. They could have amorphous electron dense granular mass freely in the matrix or small tightly packed particles clearly separated by the membrane from the matrix (Fig. 9). In one mitochondrion one or several particle sacs could be seen. Otherwise the mitochondria seemed to have normal structure (see Fig. 1).

Abnormal structures were seen also in the nucleus but only in pine needle cells and extremely seldom. Then the nucleus had vesiculated areas, in contact of which there could be needle-like accumulations.

Discussion

The top-dying and bush-like growth of the trees described here are very similar to those reported to be caused by unbalanced nutrition or nutrient deficiencies (Raitio and Rantala 1977, Silfverberg 1980). This study does not answer the question, if these changes are connected to the unbalanced fertilization or to the ultrastructural aberrations described here. The yellow chlorotic areas in conifer needles have been described earlier by Cech et al. (1961) and connected to a virus infection of the trees. The yellow mosaic has

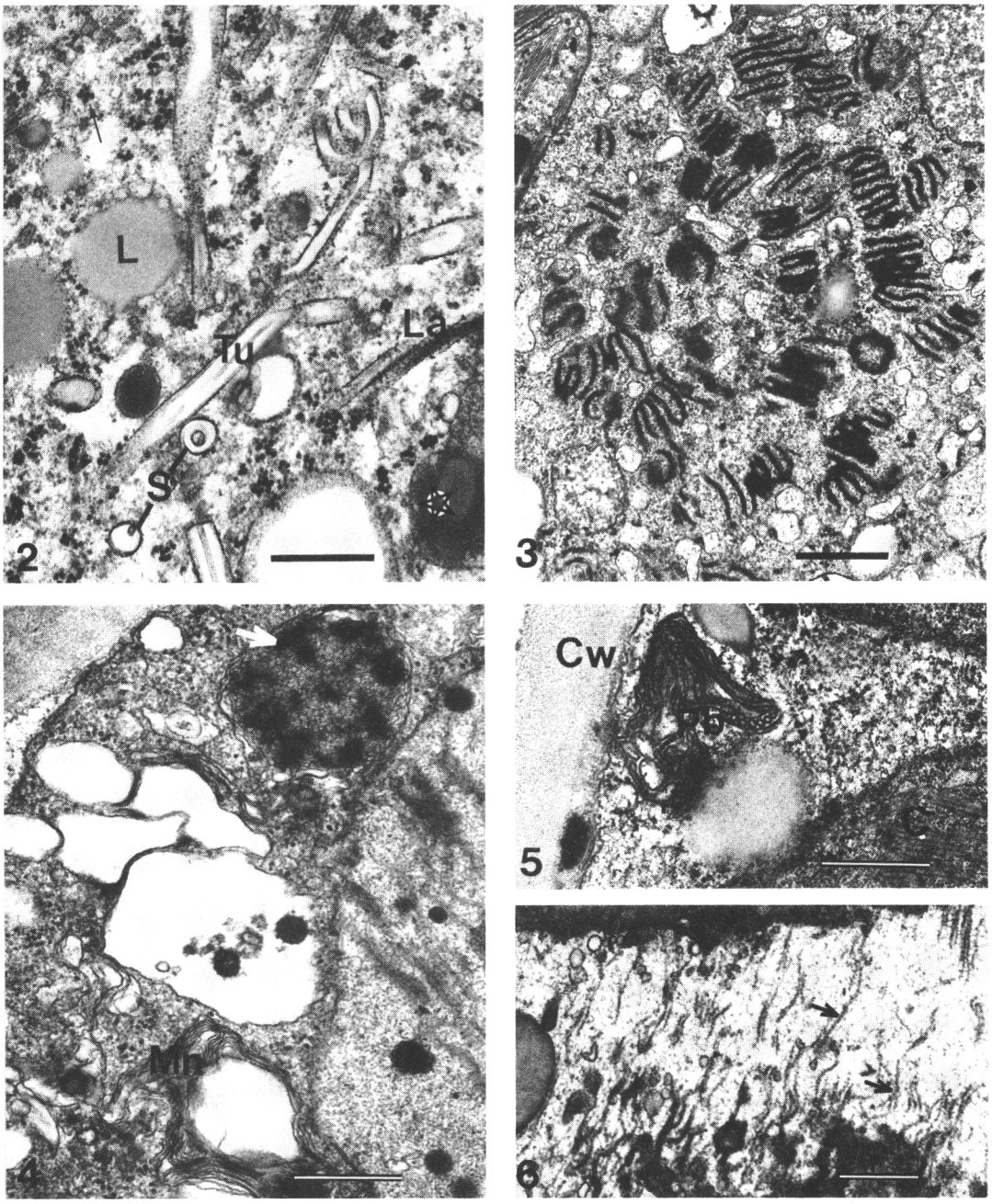


Figure 2. The cytoplasm of a spruce needle mesophyll cell showing several symptoms. The cylindrical inclusions typical of spruce are scrolls (S), tubes (Tu), and laminated aggregates (La). The aggregation of electron dense vesiculated material (star) can be seen in close contact with lipid droplets. Ribosomes (arrow) and lipid droplets (L) are present.

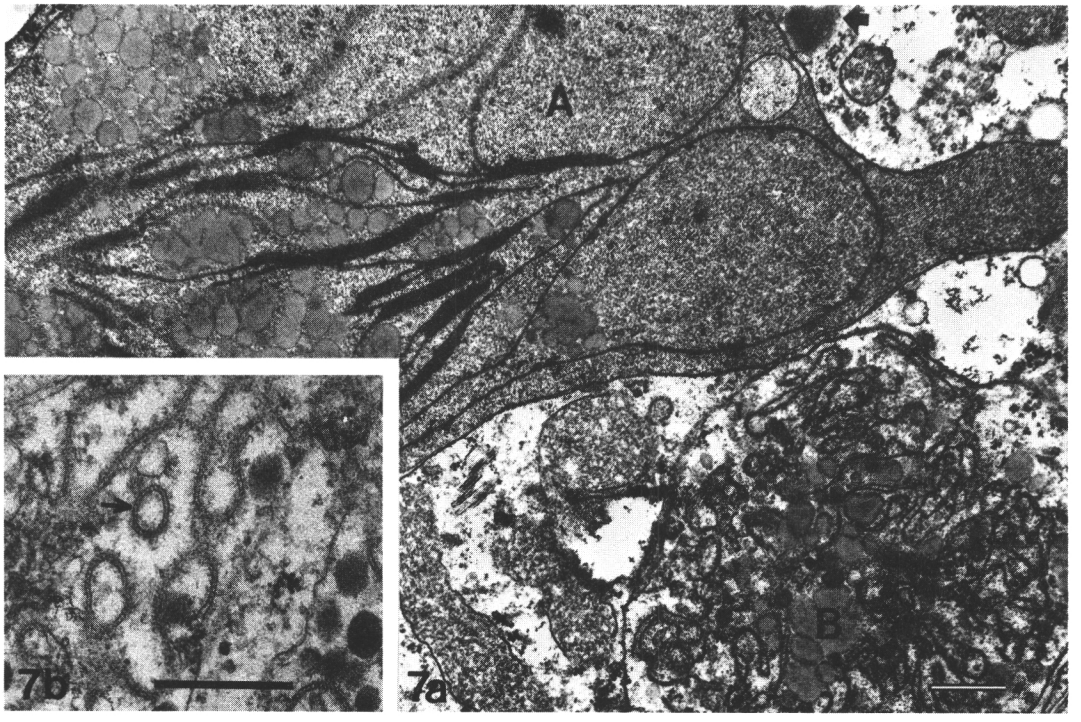
Figure 3. The pinwheel-like structure in a pine needle mesophyll cell.

Figure 4. The heavily curled filaments with black materials (arrow) in a pine needle cell. Multilayered membranes (Mn) are present, too.

Figure 5. Abnormal paramural body (Pb) in a pine needle cell. Part of chloroplast (C) and cell wall (Cw) are present.

Figure 6. Part of a pine needle cell showing electron-opaque area, in which a lot of flexuous rods (arrows) are distinguished.

All bars = 500 nm



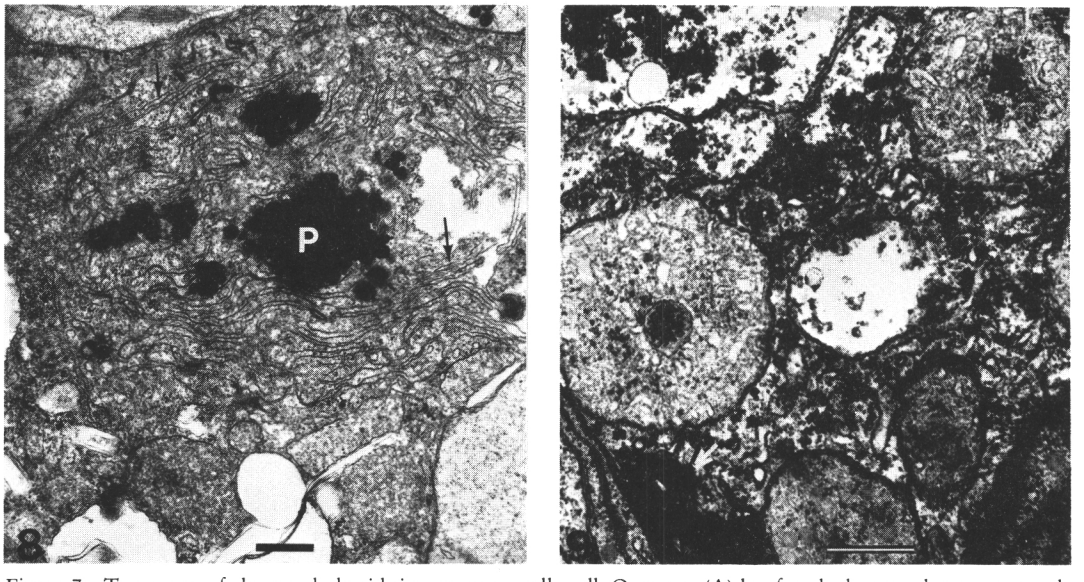


Figure 7a. Two types of aberrated plastids in a spruce needle cell. One type (A) has fused, electron-dense grana and long, circulating stroma lamellae. The other type (B) has a pellucid stroma and heavily curved thylakoids without any grana. Similar types exist in pine needle cells, too. Aggregations of electron dense material (arrow) near the chloroplasts are present.

Figure 7b. The later stage of degeneration of plastid type B in Fig. 7a. The envelopes have disappeard. Undulating or circling bands, which resemble a hairy string of pearls (arrow) are in the place of thylakoids.

Figure 8. The third type of aberrated plastid in a spruce needle cell. The undulating thylakoids have no grana. At last only fibrous material (arrows) and plastoglobuli (P) can be seen in the place of plastid. The type occurs also in pine needle cells.

Figure 9. The mitochondria in a pine needle cell. The upper one has amorphous material without membrane. The lower one has particles enveloped in a sac. The multilayered membranes (arrow) can be seen in the cytoplasm.

All bars = 500 nm.

not been described as a symptom of nutrient deficiencies or unbalanced nutrition. In this material it was frequent in trees which had needles with virotic ultrastructural aberrations and is probably due to virus infection.

The cytopathological changes reported in this study have not been described earlier in conifer needle cells with the exception of the heavily curled filaments mentioned by Soikkeli (1981). Then the structures were suspected to be connected to the infection of the trees growing in the area having low level of air pollutants. The function of the curled filaments observed in the cytoplasm and in chloroplasts from the early phase of the symptom complex in conifer needles is difficult to explain. Probably they in some way are related to virus synthesis. Similar structures have not been mentioned in broad-leaved infected plants. The paramural bodies and multilayered membranes are also distinguished at the early phase of the symptoms in needle cells. Corresponding structures have been reported earlier e.g. by Hari (1980) in viroid-infected plants, where the structures may have implications relating to the sites of activity of the viroid replication cycle.

Inclusion bodies are defined as intracellular structures produced *de novo* as a result of viral infections. They may contain virus particles, virus-related materials, or cell components or mixtures of these components (Martelli and Russo 1977, Edwardson and Christie 1978). Many inclusions are distinctive occurring consistently within a virus group. At present the inclusions of the plant reovirus, caulimovirus, closterovirus, and potyvirus groups are known to be so specific that they can be used for diagnosis of these groups (Edwardson and Christie 1978). The cylindrical inclusions found in this study resemble those typically induced by all members of the potyvirus group (Edwardson and Christie 1978) thus referring to the infection of conifers with potyviruses. But, because all the symptoms described here could be seen in the same cell, it is plausible, that the needles in this study have a mixed infection.

A variety of ultrastructural aberrations have been found in chloroplasts of virus-infected plant tissue (e.g. Hatta and Matthews 1974, McMullen et al. 1978). The cells with more than one aberration type of plastid ('the mixed cells') like in needle cells here have been earlier reported only in a few papers (Arnott et al. 1969, McMullen et al. 1978). Arnott et al. (1969) explain 'the mixed cell' phenomenon to be due to differences in interaction between virus and the plastome of individual plastids, to limiting of the normal development or the maintenance of plastids as the result of virus synthesis or to production of various phenotypes during the plastid degeneration. In conifer needles the chloroplast aberrations were so different that they probably are not intermediate steps of one kind of degeneration. It is also probable, as mentioned also by McMullen et al. (1978), that viruses can influence the genetic condition of individual plastids. On the other hand, in the case of this material 'the mixed cells' may also be a sign of the infection with several different viruses.

Chloroplasts, mitochondria, and nucleus are mentioned as the sites of synthesis and assembly of the viruses (e.g. Esau 1979, Schlegel 1967). According to this study it seems that the synthesis and assembly of viruses in conifer needle cells occur more likely in cytoplasmic membraneous structures, chloroplasts and/or mitochondria than in the nucleus where the symptoms were seen only rarely.

The aggregates of virus particles are often described in virus infected plant leaves (Arnott et al. 1969, Esau 1979, McMullen and Gardner 1980). In this material the clear particle aggregations could not be found. This can be due to that observations were made from green needles, where the infection probably is at the early stage. The long flexuous particles seen in some cases in pine needle cells in electron-opaque areas of the cytoplasm may be viruses.

I cannot yet answer the basic question, why the described disease is frequent in the studied altered environments and probably almost absent in clean natural forests. The difference could be due to the decreased resistance of trees exposed to low level of air pollutants or trees with unbalanced nutrition. On the other hand, the environmental factors dealt with here may affect the physiology of trees making them more tempting to the insects, which may act as vectors of the disease.

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References

ARNOTT, H. J., ROSSO, S. W. & SMITH, K. M. 1969. Modification of plastid ultrastructure in tomato leaf cells infected with tobacco mosaic virus. J. Ultrastruct. Res. 27: 149—167.

BIDDLE, P. G. & TINSLEY, T. W. 1968. Virus diseases of conifers in Great Britain. Nature 219: 1387—1388.

BLATTNY, C. 1939. Virová albikace u smrku (*Picea excelsa*). Ochrana rostlin 15: 53—54.

— 1948. Poznámky k virosam jehlicin. Ochrana rostlin 21: 26—29.

ČECH, M., KRALIK. O. & BLATTN, C. 1961. Rod-shaped particles associated with virosis of spruce. Phytopathology 51: 183—185.

ČERNY, A., LUDVIK, J., HERVERT, V. & BLATTNYSR C. 1977. Vicebarevná zakrslost smrku a souvislost tohoto ochuravěni s kalamitnim rozšiřenim václavky na výchdnim Slovensku. Ceská Mycologie 31: 126—131.

EDWARSON, J. R. & CHRISTIE, R. G. 1978. Use of virus-induced inclusions in classification and diagnosis. Ann. Rev. Phytopathol. 16: 31—55.

ESAU, K. 1979. Beet yellow stunt virus in cells of *Sonchus oleraceus* L. and its relation to host mitochondria. Virology 98: 1—8.

HARI, V. 1980. Ultrastructure of potato spindle tuber viroidinfected tomato leaf tissue. Phytopathology 70: 385—387.

HARRISON, B. D. 1964. Infection of Gymnosperms with nematodetransmitted viruses of flowering plants. Virology 24: 228—229.

HATTA, T. & MATTHEWS, R. E. F. 1974. The sequence of early cytological changes in chinese cabbage leaf cells following systemic infection with turnip yellow mosaic virus. Virology 59: 383—396.

MARTELLI, G. P. & RUSSO, M. 1977. Plant virus inclusion bodies. Adv. Virus Res. 21: 175—266.

McELROY, F. D., BROWN, D. J. F. & BOAG, B. 1977. The virusvector and damage potential, morphometrics and distribution of *Paralongidorus maximus*. J. of Nematology 9: 122—130.

McMULLEN, C. R. & GARDNER, W. S. 1980. Cytoplasmic inclusions induced by wheat streak mosaic virus. J. Ultrastruct. Res. 72: 65—75.

— , GARDNER, W. S. & MYERS, G. A. 1978. Aberrant plastids in barley leaf tissue infected with barley stripe mosaic virus. Phytopathology 68: 317—325.

RAITIO, H. & RANTALA, E-M. 1977. Männyn kasvuhäiriön makro- ja mikroskooppisia oireita. Oireiden kuvaus ja tulkinta. Summary: Macroscopic and microscopic symptoms of a growth disturbance in Scots pine. Description and interpretation. Commun. Inst. Fenn. 91(1): 1—32.

SCHLEGEL, D. E., SMITH, S. H. & de ZOETEN, G. A. 1967. Sites of virus synthesis within cells. Ann. Rew. Phytopathol. 5: 223—246.

SILFVERBERG, K. 1980. Kuusen kasvuhäiriö ja hivenravinteet. Abstract: Micronutritional growth disorder in Norway spruce. Folia For. 432: 1—13.

SOIKKELI, S. 1978. Seasonal changes in mesophyll ultrastructure of needles of Norway spruce (*Picea abies*). Can. J. Bot. 56: 1932—1940.

— 1980. Ultrastructure of the mesophyll in Scots pine and Norway spruce: seasonal variation and molarity of the fixative buffer. Protoplasma 103: 241—252.

— 1981. The effects of chronic urban pollution on the inner structure of Norway spruce needles. Savonia 4: 1—10.

YARWOOD, C. E. 1959. Virus increase in seedling roots. Phytopathology 49: 220—223.

Total of 22 references

SESSION 4.

NUTRITIONAL SURVEYS OF GROWTH DISTURBANCES

GROWTH DISTURBANCES AND NEEDLE AND SOIL NUTRIENT CONTENTS IN A NPK-FERTILIZED SCOTS PINE PLANTATION ON A DRAINED SMALL-SEDGE BOG

Hannu Mannerkoski and Toyohiro Miyazawa

This paper describes the results obtained from an investigation into the effects of fertilization on the height development and growth disturbances of a Scots pine (*Pinus sylvestris*) plantation and on the nutrient status of the surface peat layer and pine needles on a drained small-sedge bog in Central Finland. The study area was drained in winter 1966—67. In spring 1968 2 + 1-year-old pine transplants were planted in the experimental field, each receiving a spot fertilization of 30 g NPK-fertilizer (14-8-8). In spring 1976 a series of four different refertilization treatments (O, P, PK and NPK), altogether 72 plots, was set up. The fertilizers applied were superphosphate, potassium salt and ammonium nitrate with lime.

Fertilization with P alone revealed a pronounced increase on the 1979 height increment of the trees, although much better results were obtained with PK and NPK. N fertilizer had no significant effect on the foliar N contents, whereas P and K fertilizers markedly increased the P and K concentrations of needles, respectively. The B concentration of needles showed a stepwise decrease in the order of fertilization treatments O, P, PK, and NPK. Fertilization did not have any effect on the Cu concentration of needles, but it decreased the foliar Zn concentration in all cases. All micronutrients studied, however, lay above their critical deficiency levels for Scots pine. Macronutrient fertilizers had little or no positive effects on the N, P and K status of peat. Fertilization tended to increase the exchangeable Ca status of peat without an appreciable effect on the pH values. Fertilization slightly decreased the acid-soluble Zn and increased the acid-soluble Cu content in peat. Fertilization, especially with PK and NPK, increased markedly the amount of growth disturbances. They were preceded by decreased B and increased K concentration in needles and increased Cu and decreased Zn contents (kg/ha) in peat.

Introduction

During the last ten years growth disorders have been frequently observed in Scots pine particularly on drained and fertilized peatlands. According to the results obtained in a series of investigations carried out by the Finnish Forest Research Institute, micronutrient deficiencies, especially of boron, have been suspected as the most likely cause (e.g. Veijalainen 1975, Huikari 1977, Kolari 1979, Raitio 1979). Apical dieback, increased susceptibility to disease, crooked, distorted stems and retarded growth as well as anatomical microscopic deformation may indicate characteristic micronutrient deficiencies (Veijalainen 1975, Raitio and Rantala 1977, Kolari et al. 1977). The growth disorders also occur on moderately fertile abandoned farmlands (Veijalainen 1978, Silfverberg 1980). Veijalainen's approach to the causal reason for the growth disturbances arrived at a dilution phenomenon caused by increased growth after intensive drainage and fertilization. It is a well-known fact that arable peat soils are generally deficient in boron, copper and occasionally in other micronutrients as well (Kurki 1972).

Similar results are available in other Nordic countries. In Norway some of the growth disturbances occurring on afforested open peatlands were caused by micronutrient deficiencies, especially of boron (Braekke 1977, 1979). It must be pointed out that growth disturbances due to other factors are also possible on some sites.

The aim of this investigation is to find out the effect of fertilization on the nutrient economy of a Scots pine plantation by analysing nutrients in needles and in surface peat. The growth disturbance inventory was carried out three years after the nutrient analyses. The correlation of growth disturbance with nutrient characteristics can thus be studied and tested as prediction of growth disturbances.

The experimental field has been set up by the Department of Peatland Forestry, University of Helsinki, under guidance of Prof. Leo Heikurainen. The measurements and sampling was done by Mr. Toyohiro Miyazawa B. Sc., the computation was done by both writers, and this paper was written mainly by Mr. Hannu Mannerkoski Lic. For. The chemical analyses were made by Viljavuuspalvelu Oy (Soil Testing Service Co.), and the study was subsidized by the Foundation of Kemira Co., to which we express our sincerest gratitude.

Material and methods

The experimental field is located in Central Finland near the Forestry Station of the University of Helsinki at Hyytiälä in Korkeakoski Forest District, some 60 km north of Tampere (61°50′ N, 24°20′ E). In 1967 the Department of Peatland Forestry, University of Helsinki, started and experiment with an aim of assessing the influence of different ditch spacings and ditch depths on the development of the Scots pine plantation. The peatland site type was originally ombrotrophic small-sedge bog with *Sphagnum fuscum* rich hummocks. Average annual precipitation amounts to about 600 mm in the region. The permanent snow cover is usually formed in November or December, melting away in the early May.

The study area was drained in winter 1966—67. On the basis of the ditch depths (40, 70 and 100 cm) the experimental area was divided into three blocks, within each of which three different ditch spacings (10, 25 and 40 m) were employed at random using two replications. An exact half of each block was furrowed beforehand at ca. 10 m intervals, 35 cm in depth. In spring 1968 2 + 1-year-old pine transplants were planted in the experimental field, each receiving 30 g of spot fertilization (N-P-K; 14-8-8 %) (Fig. 1 and Päivänen 1974).

In spring 1976 a series of four different refertilization treatments (O, P, PK and NPK) was set up by cutting into halves the existing furrowed and unfurrowed plots. These four fertilization treatments had two replications in each ditch spacing within the block, one in the furrowed half and the other in the unfurrowed (Fig. 1). The fertilizers used were:

N — 385 kg/ha ammonium nitrate with lime (26 % N, 6 % Ca, 3 % Mg)
P — 575 kg/ha superphosphate (9 % P, 20.5 % Ca)
K — 150 kg/ha potassium salt (50 % K, 48 % Cl)

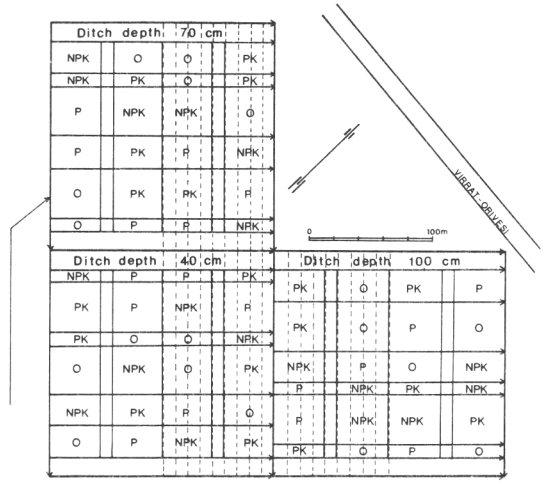


Figure 1. The experimental field. The lines with arrowhead indicate ditches, the others boundaries between refertilization plots. The broken lines indicate furrows. The refertilization treatments have been explained in the text.

The total number of the newly-designed experimental plots was 72. The total area of the field was 10.26 ha including marginal buffer strips.

Height and height increment of trees were measured in autumn 1979. In autumn 1979 peat samples (mixed from three subsamples per plot) from the surface layers 0—10 and 10—20 cm and needle samples (mixed from the south facing second and third whorl branches of six trees per plot) were taken and stored. The peat samples were then analyzed for total N, total acid ammonium acetate soluble P, total and exchangeable K, exchangeable Ca, water soluble B, and acid soluble Cu and Zn, and the needle samples for N, P, K, B, Cu and Zn. The nutrient concentrations in peat have been converted into absolute amounts (kg/ha) on the basis of bulk density measurements.

In summer 1982 the occurrence of growth disturbances was investigated in this experimental area classifying the trees with disorders in the following way:

1. All needles green
2. Brown (dry, dead) needles on branches
3. Brown (dry, dead) needles on terminal shoot
4. The whole tree died during the year 1982.

The most obvious reason for the dying of needles in spring 1982 (classes 2—4) was the fungal disease caused by *Gremmeniella abietina*.

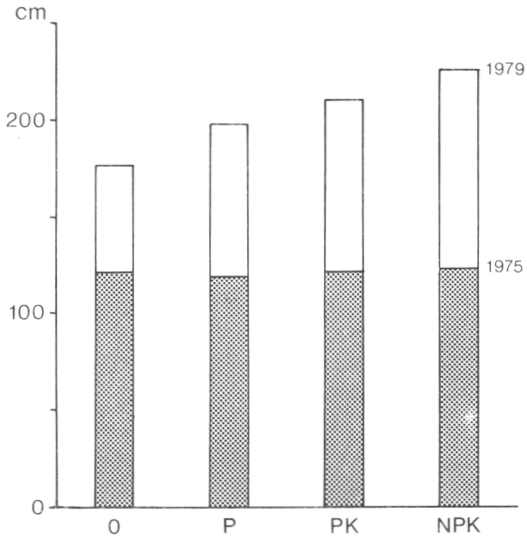


Figure 2. The height of Scots pine on different refertilization treatments (see page 86) before refertilization in autumn 1975 and in autumn 1979 four growth periods after refertilization.

Results

Before refertilization the height of trees was, on average, the same on every refertilization treatment (Fig. 2). Of course there was variation caused by furrowing and ditch spacing. Already P alone had a significant effect but because the site is also poor in N, the best results have been obtained with NPK-fertilization (Fig. 2). This can be seen more clearly from the development of height growth (Fig. 3).

Growth disturbances started to appear some years after the refertilization in 1976. On unfertilized plots the proportion of trees with disturbances is under 1 %, but it rises with fertilization. P alone does not have any pronounced effect but PK and, especially, NPK have increased the proportion of trees with disturbances on average to 7—8 % (Table 1).

The variation among the plots of the same fertilization treatment was, however, quite large, for instance on NPK-plots from 1.5 to 17.6 % and on 0-plots from 0.0 to 2.6 %.

Fertilization did not have any effect on the N concentration of needles, but P and K concentrations have increased on plots fertil-

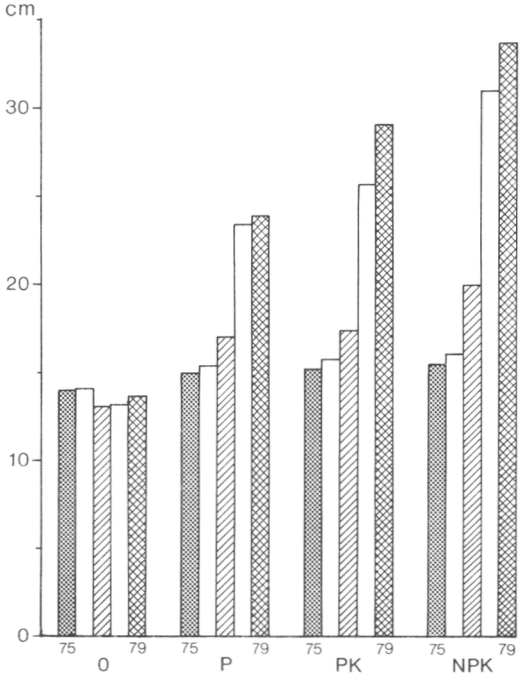


Figure 3. The yearly height increment of Scots pine on different refertilization treatments (see page 86) in growth period 1975 before refertilization and in growth periods 1976—79 after the refertilization in spring 1976.

Table 1. The proportion of trees with growth disturbances in summer 1982 on different refertilization treatments classified according to the *Gremmeniella* damage. F-values of the main effect of fertilization in the analysis of variance are also presented.

Fertilization treatment 1)	Disturbances in % of trees living in 1981 Disturbance class 1) 1	2	3	4	Total
O	0.5	0.4	0.1	0.0	1.0
P	0.4	1.2	0.8	0.2	2.6
PK	1.1	2.9	2.2	0.5	6.8
NPK	1.3	2.9	3.1	1.1	8.4
F(3,36)	6.44**	14.14***	17.44***	17.62***	21.34***

1) See pages 86 and 87

Table 2. The concentrations of different nutrients in Scots pine needles on different refertilization treatments. F-values of the main effect of fertilization in the analysis of variance are also presented.

Fertilization treatment 1)	Nutrient concentrations in needles N %	P mg/g	K mg/g	B ppm	Cu ppm	Zn ppm
O	1.77	1.97	7.11	25.4	4.88	91.6
P	1.72	2.45	7.81	21.1	4.56	71.9
PK	1.77	2.52	9.08	20.2	4.77	76.8
NPK	1.87	2.46	8.76	14.2	4.39	73.6
F(3, 36)	2.41	26.45***	17.63***	48.42***	1.57	9.28***

1) See page 86

Table 3. The amounts of different nutrients in the surface peat layer (0—20 cm) on different refertilization treatments. F-values of the main effect of fertilization in the analysis of variance are also presented.

Fertilization treatmen 1)	Amounts of nutrients in surface peat (0—20 cm), kg/ha Total N	P	Exchangeable K	Ca	Soluble K	P 2)	B 3)	Cu 4)	Zn 4)
O	1043	97	47	314	42	14	0.28	0.40	4.7
P	812	93	35	439	30	14	0.27	0.55	4.3
PK	917	102	44	404	38	15	0.24	0.61	3.9
NPK	858	93	43	409	38	14	0.29	0.62	3.7
F(3, 36)	3.12	0.79	5.45**	7.40***	6.00**	1.19	2.17	16.61***	3.65*

1) See page 86
2) Extracted with acid ammonium acetate
3) Extracted with water
4) Extracted with 2 N HCl from ash

ized with respective nutrients (Table 2). Fertilization, especially NPK-fertilization, has decreased the B concentration in needles. The concentration of Zn is also lower on fertilized than on unfertilized plots.

The amounts of nutrients in peat are presented in Table 3. We have used the unit kg/ha in 20 cm thick surface peat layer. Fertilization did not have any significant effect on the amounts of N, P or K in peat. The amounts given by fertilizer application have already been used by plants or leached away. The increase in the amount of Ca in peat, however, is almost the same as the dosage of superphosphate given in refertilization. There is some indication of the increase of Cu in peat although superphosphate should not contain remarkable amounts of this element. The amounts of Zn have decreased after refertilization. The amounts of nutrients in peat do not show any clear correlation with the concentrations of respective nutrients in needles.

The most important factor causing growth disturbances was fertilization (see Table 1). The correlation coefficients between the total proportion of disturbed trees and different chemical characteristics of peat and needles are found in Table 4. The variables in Table 4 were largely intercorrelated and therefore, it was necessary to calsulate partial correlation coefficients by eliminating the effects of other variables correlating both with the growth disturbances and the variable to be tested. However, we did not eliminate the effect of variable "fertilization", because fertilization has produced most of the variation found in different variables. The effect of derived variables (e.g. N/B) should also not be eliminated from their factors (N or B) or *vice versa.* The partial correlations indicated that fertilization has an increasing effect on the amount of growth disturbances which is not explained by the other variables measured in this investigation which correlate with growth disturbances. Most surprising is the

Table 4. Variables which correlate significantly with the proportion of trees with growth disturbances. Correlation coefficients and partial correlation coefficients after elimination of the effect of listed variables are presented.

Variable No.	Name	Correlation coefficient single	partial	Eliminated variables in partial correlation
1	Fertilization treatment	.600***	.255*	2, 3, 4, 5, 6, 7, 8, 13
2	Cu, kg/ha in peat	.518***	.335**	3, 4, 5, 6, 12
3	K, ppm in needles	.488***	.308*	2, 4, 7, 10, 12, 13
4	N/B in needles	.476***	.224	2, 3, 7, 12
5	B, mg/kg in needles	—.440***	—.288*	2
6	N/K in needles	—.376**	—.140	2, 7, 13
7	P, mg/g in needles	.349**	—.122	3, 4, 6, 10, 13
8	Zn, kg/ha in peat	—.346**	—.440***	12
9	Ditch depth (block)	.335**	.213	2, 7, 11, 12
10	N, % in needles	.310**	—.179	3, 7, 11, 12
11	P/K in needles	—.287*	—.163	10, 12
12	Water content in surface peat (0—10 cm), vol.-%	—.278*	.046	2, 3, 4, 10, 11
13	Ca, kg/ha in peat	.263*	.183	3, 6, 7

positive correlation between growth disturbances and the amount of Cu in peat. The concentration of K in needles has a positive correlation, too. On the other hand, the lack of Zn in peat and that of B in needles has increased the proportion of disturbed trees.

Discussion

The area under investigation was a drained ombrotrophic bog on which pines had been planted 12 years ago and which had been refertilized with O, P, PK and NPK treatments four years before sampling for nutrient analyses. Three years after that the inventory of growth disturbances was made.

The concentrations in pine needles of macronutrients studied were higher than usually reported in literature from equivalent site types (Paarlahti et al. 1971, Braekke 1977, Paavilainen 1977, Raitio and Rantala 1977, Raitio 1979). Possible cause for this might be the NPK- spot fertilization, although the amount of fertilizer was small (30 g/transplant) and it was applied 12 years ago. The concentrations of B were in all cases over the critical deficiency level, 7—10 ppm (cf. Braekke 1979, Kolari 1979). The concentrations of Cu and Zn were also higher than those reported by Raitio and Rantala (1977) and Raitio (1979). Paarlahti et al. (1971) and Veijalainen (1977) have found about twice as high Zn concentrations than we, although Veijalainen reported from another experiment a little smaller values than ours. Similar concentrations of Cu and Zn have also been found fertilized areas (cf. Braekke 1977, Silfverberg 1979). The effect of fertilization on the concentrations of macro- and micronutrients was quite similar to that found in earlier studies (cf. Paarlahti et al. 1971, Paavilainen 1977, Veijalainen 1977). The concentration of Ca in needles was not analysed, and so we were not able to calculate Ca/B-ratio which Raitio (1979) found important in relation to growth disturbances.

The amounts of nutrients in peat were expressed as kg/ha in surface peat (0—20 cm) (cf. Braekke 1977). Generally it is more advisable to use dimensions mass unit per unit volume of peat or per unit area with a fixed depth because these show exactly how much there are nutrients on the site in question. The unit mg/l of peat powder usually used in Finland (e.g. Paarlahti et al. 1971, Kolari et al. 1977, Veijalainen 1977, Raitio 1979), or the unit mg/g dry peat, is not very useful without the knowledge of the natural bulk density, too. Braekke (1977) presents almost similar amounts of N and Cu, twice so high of Zn, a little higher of K, and only half of Ca and P that we found. If we compare the units mg/l of our study (not presented) to the others they agree quite well with the exception of Zn concentrations which are only half as high as those reported by Paarlahti, et al. (1971) or Veijalainen (1977). The Zn concentrations in the study of Kolari et al. (1977) were, however, a little smaller than ours.

By studying the relations of nutritional characteristics to the proportion of growth disturbances in this experiment we must remember that they were analysed at different times. The results in Table 4 can therefore be used to describe the value of different characteristics in prediction of coming growth disturbances. The needle samples were taken from healthy trees. There were no visible growth disturbances at the time of needle and peat sampling three years before the growth disturbance inventory. These probably explain, at least partly, the high concentrations of B found in needles. However a low B concentrations proved to be a prediction of high proportion of growth disturbances, although they were not very common in this experiment. The best predictor was, in fact, the amount of Zn in peat although the correlation was not very high. An equal relation of Zn and growth disturbances has been found by Kolari et al. (1977), but that reported by Raitio (1979) is just an opposite. Raitio and Rantala (1977) found the deficiency of Zn in needles to increase growth disturbances. In Raitio's (1979) study the content of Cu in peat was higher on growth disturbance area than on the others, but Kolari et al. (1977) did not find any differences. In our study the amount of Cu in peat was the second best predictor of growth disturbances; the higher the concentration the more growth disturbances. The concentration of K in needles was in positive correlation with the proportion of disturbed trees (cf. Raitio and Rantala 1977, Raitio 1979). There seems to be many reasons to the growth disturbances (see Kolari et al. 1977, Veijalainen 1981), although in many studies the deficiency of B has been concluded to be the main reason (e.g. Braekke 1977, Raitio 1979).

As a whole the growth disturbances were not very common on the experimental field studied now. Growth disturbances were almost totally induced by refertilization with PK or NPK. On unfertilized plots or those fertilized only with P there were only few disturbed trees. On the other hand it must be remembered that the site type is so poor in nutrients that trees cannot survive totally without fertilization (the 0-plots had been spotfertilized at the time of planting). If we will afforestate so poor peatlands and grow the trees with fertilizers we must find a good combination of different nutrients in fertilizers and most probably also add micronutrients to avoid growth disturbances.

References

BRAEKKE, F. H. 1977. Fertilization for balanced mineral nutrition of forests on nutrient-poor peatland. Lyhennelmä: Turvemaiden tasapainoinen lannoitus. Suo 28(3): 53—61.

— 1979. Boron deficiency in forest plantations on peatland in Norway. Medd. Nor. inst. skogforsk. 35 (3): 213—236.

HUIKARI, O. 1977. Micro-nutrient deficiencies cause growth disturbances in trees. In: Nutrient cycle in tree stands, Nordic Symposium. Silva Fenn. 11(3): 251—255.

KOLARI, K. K. 1979. Hivenravinteiden puute metsäpuilla ja männyn kasvuhäiriöilmiö Suomessa — kirjallisuuskatsaus. Abstract: Micro-nutrient deficiency in forest trees and dieback of Scots pine in Finland — a review. Folia For. 389: 1—37.

— , PAAVILAINEN, E. & RAITIO, H. 1977. Männyn juuristosuhteista Kivisuon kasvuhäiriöalueella. Abstract: Pine roots and growth disturbances. Folia For. 313: 1—16.

KURKI, M. 1972. Suomen peltojen viljavuudesta II. Referat: Über die Fruchtbarkeit des finnischen Ackerbodens auf Grund der in den Jahren 1955—1970 durchgeführten Bodenfruchtbarkeitsuntersuchungen. Helsinki, Yhteiskirjapaino Oy. 182 pp.

PAARLAHTI, K., REINIKAINEN, A. & VEIJALAINEN, H. 1971. Nutritional diagnosis of Scots pine stands by needle and peat analysis. Seloste: Maa- ja neulasanalyysi turvemaiden männiköiden ravitsemustilan määrityksessä. Commun. Inst. For Fenn. 74(5): 1—58.

PAAVILAINEN, E. 1977. Effect of fertilization on nutrient content in needles and litter fall of Scots pine on dwarf shrub pine swamp. In Nutrient cycle in tree stands, Nordic Symposium. Silva Fenn. 11 (3): 246—251.

PÄIVÄNEN, J. 1974. Sarkaleveyden ja naveroinnin vaikutus pohjavesipinnan syvyyteen ja männyntaimiston kehitykseen lyhytkortisella nevalla. Summary: The effect of ditch spacing and furrowing on the depth of the ground water table and on the development of a Scots pine plantation on small-sedge bog. Silva Fenn. 8 (4): 215—224.

RAITIO, H. 1979. Boorin puutteesta aiheutuva kasvuhäiriö metsitetyllä suopellolla. Oireiden kuvaus ja tulkinta. Abstract: Growth disturbances of Scots pine caused by boron deficiency on an afforested abandoned peatland field. Description and interpretation of symptoms. Folia For. 412: 1—16.

— & RANTALA, E-M. 1977. Männyn kasvuhäiriön makro- ja mikroskooppisia oireita. Oireiden kuvaus ja tulkinta. Summary: Macroscopic and microscopic symptoms of a growth disturbance in Scots pine. Description and interpretation. Commun. Inst. For. Fenn. 91(1): 1—32.

SILFVERBERG, K. 1979. Männyn kasvuhäiriön ajoittuminen ja alkukehitys turvemaan boorinpuutosalueella. Abstract: Phenology and initial develop-

ment of a growth disorder in Scots pine on boron deficient peatland. Folia For. 396: 1—19.
— 1980. Kuusen kasvuhäiriö ja hivenravinteet. Abstract: Micronutritional growth disorder in Norway spruce. Folia For. 432: 1—13.
VEIJALAINEN, H. 1975. Kasvuhäiriöistä ja niiden syistä metsäojitusalueilla. Summary: Dieback and fertilization on drained peatlands. Suo 26 (5): 87—92.
— 1977. Use of needle analysis for diagnosing micronutrient deficiencies of Scots pine on drained peatlands. Seloste: Neulasanalyysi männyn mikroravinnetilanteen määrityksessä turvemailla. Commun. Inst. For. Fenn. 92(4): 1—32.
— 1978. Metsäpuiden latvakadon esiintymisestä Suomessa. Summary: Occurrence of die-back of forest trees in Finland. Metsäntutkimuslaitoksen suontutkimusosaston tiedonantoja 1: 1—22.
— 1981. Hivenlannoituksen vaikutus istutusmännikön kehitykseen turvemaalla. Summary: Long-term responses of Scots pine to micronutrient fertilization on acid peat soil. Folia For. 477: 1—15.

Total of 17 references

FOLIAR RESPONSES CAUSED BY DIFFERENT NITROGEN RATES AT THE REFERTILIZATION OF FERTILE PINE SWAMPS

Eero Paavilainen and Pekka Pietiläinen

The material was collected in the experimental fields of Köhisevä and Vesikkosuo established in Bothnia, western Finland, by the Department of Peatland Forestry at the Forest Research Institute. In both areas an experiment was established in a pine seedling stand, in a young pine thinning stand and an old pine thinning stand.

In refertilization different amounts of nitrogen (0, 50, 100, 200, 400, 600 kg N/ha) together with PK were used. Also micronutrient mixture was applied in the experiments.

The needle analysis after two growing seasons after refertilization showed that by using high nitrogen rates the nutrient ratios of pine needles change essentially on fertile peat soils. Refertilization with 400 kg N/ha brought on phosphorus deficiency and as little as 200 kg N/ha potassium deficiency although the fertilizer besides nitrogen also contained phosphorus (43 kg P/ha) and potassium (83 kg K/ha).

The effect of high nitrogen rates on the boron, copper and molybdenum contents of needles remained rather small. The boron and molybdenum contents of needles increased rapidly when using fertilizers containing these nutrients. The copper-containing micronutrient mixture hardly at all affected the copper content of needles during two growing seasons.

The chlorophyll a and b fractions correlated negatively with the foliar phosphorus levels at Köhisevä experimental field and chlorophyll b positively with the foliar copper level at Vesikkosuo experimental fields. The refertilization did not affect the cell wall thickness or cell diameter of the supportive tissue by the vascular bundle or the center of the supportive tissue. The cell diameter was always larger at the center of the supportive tissue than by the vascular bundle.

At Köhisevä experimental field the cell wall thickness increased with the age of the stand. At Vesikkosuo the cell wall thickness decreased with the age of the stand. The cell diameters behaved *vice versa*.

Introduction

Peatlands rich in nitrogen but low in phosphorus and potassium usually benefit from PK fertilization which leads to a strong and long-lasting growth improvement. On such naturally fertile peat soils nitrogen application with phosphorus and potassium is recommended only in fully stocked and well-growing forests of old drainage areas (e.g. Huikari & Paavilainen 1972, Paavilainen 1979a). The role of nitrogen at refertilization is not adequately known.

When considering the nitrogen requirements at the refertilization of peatlands, attention should be focused on the nutrient ratios. The mere nitrogen refertilization may, both on poor and fertile peatlands, change the nutrient ratios unfavourable and result in a growth decline of stands (e.g. Paavilainen 1977, 1978, 1979b, Kaunisto and Paavilainen 1977, Raitio 1981). Imbalance both of main nutrient and micronutrient concentrations may cause growth disturbances (Huikari 1974, 1977, Kaunisto & Paavilainen 1977, Veijalainen 1975, Raitio 1981). Especially important is to know how the nitrogen rates affect the nutrient ratios and the development of assimilating foliage.

Only one experimental series, carried out on a cottongrass pine swamp, reports on the effect of different nitrogen rates applied with phosphorus and potassium on peatland (Paavilainen 1974). No results dealing with the responses caused by nitrogen rates at the refertilization of fertile peat soils have been published.

The aim of this investigation is to find out how the foliage of stands on fertile pine swamps is affected by nitrogen refertilization in addition to phosphorus, potassium and micronutrients. The investigated nitrogen rates range from 50 kg up till 600 kg per hectare.

The foliar dry weight, nutrient and chlorophyll levels as well as needle structure two growing seasons after refertilization were studied. Later the observed foliar responses will be compared to the changes in the growth of stands.

Material and methods

Experimental fields

The material was collected in the experimental fields of Köhisevä (= K, location 64°5′N, 26°36′E) and Vesikkosuo (= V, location 64°4′N, 26°41′E) established in Bothnia, western Finland, by the Department of Peatland Forestry at the Forest Research Institute. In both areas an experiment was established in

— pine seedling stand
— young pine thinning stand
— old pine thinning stand.

The peatland site type was in Köhisevä *Carex globularis* and sedge pine swamp. In Vesikkosuo experimental field the site types were partly the same as in Köhisevä and partly cottongrass pine swamp.

The seedling stand and the young thinning stand at Köhisevä were first fertilized in 1964 with finely ground rock phosphate (13,8 % P) 600 kg/ha and muriate of potash (42 % K) 178 kg/ha. The old thinning stand at Köhisevä was fertilized in 1961 with finely ground rock phosphate 600 kg/ha and muriate of potash 200 kg/ha, in addition to which the area was fertilized with 700 kg/ha of NPK (14 % N — 7,3 % P — 8,3 % K) in 1963. The experiments at Vesikkosuo were fertilized with 600 kg/ha of finely ground rock phosphate and 200 kg/ha of muriate of potash in 1962—1965.

The following 8 refertilization treatments were replicated 2—3 times in all the six experiments:

Treatment	PK fertilizer kg/ha	Nitrogen kg/ha	Micronutrient mixture
1	—	—	—
2	500	—	—
3	500	50	—
4	500	100	100 kg/ha + 10 kg/ha fertilizer borate (14 % B)
5	500	100	—
6	500	200	—
7	500	400	—
8	500	600	—

PK fertilizer used was the granular PK for peatland forests which in addition to 8,7 % P and 16,6 % K among other things contains 0,1 % Mg, 17,7 % Ca, 2,4 % S, 0,5 % Na, 1,1 % Fe and 0,2 % B. Nitrogen was given as calcium ammonium saltpetre. The micronutrient mixture contained 1,1 % B, 12,8 % Cu, 5,5 % Mn, 9,8 % Fe, 5,5 % Zn, 1,4 % Mo and 0,7 % Na.

Nutrient analyses

Soil and needle samples were collected in each sample plot before establishing the experiments. The soil sample consisted of five subsamples (size 4 × 5 cm), and the needle sample of the last needles of the dominant canopy layer (5 trees/plot).

The averages of different nutrients per experiment before refertilization are presented in Table 1. The variation between replications was slight. Only in two

cases was it statistically significant according to the analysis of variance (soil nitrogen content in the seedling stand at Köhisevä and foliar nitrogen content in the young thinning stand at Köhisevä).

According to the needle analysis the nutrient conditions of the stands were good when the experiments were established. Only the foliar phosphorus and potassium levels in young and old thinning stands at Vesikkosuo were rather low (see e.g. Paarlahti et al. 1971).

The nitrogen content of peat was high in all the experiments. Similarly, the phosphorus content of soil was fairly high, while the K and Ca contents were relatively low (see Westman 1981).

Needle samples were taken again from the last needles of the dominant canopy layer in October 1979 i.e. two growing seasons after refertilization. The needles were analysed for N, P, K, Ca, Mg, B, Cu and Mo.

All the nutrient analyses were made by Viljavuuspalvelu Oy (Soil Testing Service Co.).

Chlorophyll determination

The frozen needle samples were thawned and cut into 1—2 mm sections. 1,0 g of the cut needle mass was put into 25 ml of 80 % acetone and homogenized with a Yastral 5000 suspensor for 30 sec. The green homogenate was filtered through Watman No. 1 filterpaper in a Buchner funnel. The cellular debris was washed and refiltered with 25 ml of 80 % acetone. The optical density of the filtrate was measured in a 1 cm cuvette against a 80 % acetone blank at wavelengths 645 and 663 nm with a Hitachi 100—40 spectrophotometer.

Calculations for chlorophyll determinations.

$$\text{mg chlorophyll a/g tissue} = [12{,}7\ (OD_{663}) - 2{,}69\ (OD_{645})] \times \frac{V}{1000 \times W}$$

$$\text{mg chlorophyll b/g tissue} = [22{,}9\ (OD_{645}) - 4{,}68\ (OD_{663})] \times \frac{V}{1000 \times W}$$

In the above equation OD is the optical density of the chlorophyll extract of the specific indicated wavelength, V the final volume of the 80 % acetone-chlorophyll extract, and W the fresh weight in grams of the tissue extrated (Mac Kinney 1941).

Table 1. Foliar and soil nutrient levels before refertilization. Needle sampling in March, 1978 and soil sampling in June, 1978.

	Seedling stand	Young thinning stand	Old tihinning stand
		Köhisevä	
Needles	(C)	(D)	(B)
N %	1,54	1,44	1,54
P %	0,23	0,19	0,19
K %	0,50	0,47	0,42
Soil			
N %	2,20	2,20	2,18
P mg/g	1,13	1,25	0,79
K mg/g	0,20	0,20	0,20
Ca mg/g	1,61	1,95	2,86
		Vesakkosuo	
Needles	(B)	(C)	(D)
N %	1,50	1,42	1,68
P %	0,22	0,16	0,15
K %	0,47	0,38	0,39
Soil			
N %	2,61	2,39	2,43
P mg/g	0,87	0,80	0,86
K mg/g	0,13	0,19	0,21
Ca mg/g	2,44	2,37	2,98

The standard errors were as follows:
Needles: N = 0,01—0,03 %, P = 0,00—0,01 %, K = 0,00—0,01 %
Soil: N = 0,03—0,09 %, P = 0,02—0,03 %, K = 0,00—0,01 %, Ca = 0,07—0,15 %.

Needle structure

The anatomical needle studies were done with a Leitz Dia Lux 20 EB light microscope. The scale in the ocular was calibrated and used to measure the cellular parameters from the cross sections of the needles. The needle sections were cut from the center of the needle by keeping the needle between two microscope slides. The one and a half cell thick cross sections were cut with a razor-blade. The cross sections were stained with a general anatomical stain (Niemelä 1974).

The anatomical parameters were measured as in Raitio and Rantala (1977) and Raitio (1981). The cell wall thickness and cell diameter was measured by the vascular bundle and at the center of the supportive tissue.

Results and discussion

Foliar dry weight

The thousand-needle biomass was increased by refertilization (Table 2). PK fertilization alone increased the dry weight of thousand needles, but the best result was obtained by applying nitrogen with phosphorus and potassium. A positive effect was gained even by 50 kg of nitrogen per hectare. As the nitrogen rate was 600 kg per hectare, the foliar dry weight was in most cases lower than on plots where 200—400 kg N/ha was used.

Table 2 also shows that the thousand-needle dry weight decreased as the stand aged. The highest dry weight was in a seedling stand and the lowest in an old thinning stand.

Table 2. Foliar dry weight two growing seasons after refertilization.

Fertilization			Dry weight of 1000 needles, g					
N	PK-fertilizer	Micronutrient mixture	Köhisevä			Vesikkosuo		
kg/ha	kg/ha	kg/ha	Seedling stand	Young thinning stand	Old thinning stand	Seedling stand	Young thinning stand	Old thinning stand
0	0	0	14,79	14,34	13,11	12,98	11,15	11,25
0	500	0	15,10	17,00	17,19	16,58	12,97	13,97
50	500	0	21,47	20,67	19,32	25,62	19,30	12,04
100	500	0	22,53	23,22	18,98	29,58	18,43	16,25
100	500	100 + 1,4 B	24,44	25,07	19,81	26,48	20,98	14,57
200	500	0	26,15	25,19	22,37	28,42	20,11	15,48
400	500	0	28,45	23,64	23,06	27,88	18,01	13,26
600	500	0	25,78	22,45	16,87	32,35	16,46	14,45
F-value and significance			5,63**	3,08*	3,53*	4,56*	2,85	0,85
Significant difference (5% risk level)			10,42	10,91	9,47	17,52	—	—

Table 3. Changes in foliar nitrogen, phosphorus and potassium levels (% of dry weight) occurring between samplings on unfertilized plots.

	Seedling stand			Young thinning stand			Old thinning stand		
	N	P	K	N	P	K	N	P	K
					Köhisevä				
March 1978	1,54	0,23	0,50	1,44	0,19	0,47	1,54	0,19	0,42
October 1979	1,55	0,19	0,49	1,33	0,18	0,44	1,62	0,17	0,44
Increase (+) or decrease (—)	+0,01	—0,04	—0,01	—0,11	—0,01	—0,03	+0,08	—0,02	+0,02
					Vesikkosuo				
March 1978	1,50	0,22	0,47	1,42	0,16	0,38	1,68	0,15	0,39
October 1979	1,71	0,19	0,44	1,65	0,14	0,36	1,63	0,14	0,40
Increase (+) or decrease (—)	+0,21	—0,03	—0,03	+0,23	—0,02	—0,02	—0,05	—0,01	+0,01

Foliar nutrient levels

In two growing seasons some changes occurred in the foliar nutrient levels irrespective of fertilization treatments. On the unfertilized plots the foliar nitrogen levels increased on four and decreased on two out of six experimental fields (Table 3). The foliar phosphorus level decreased on all experimental fields. In the young and old thinning stands at Vesikkosuo in 1979, the phosphorus level was 0,14 %, bordering on phosphorus shortage (see Paarlahti et al. 1979). Only few changes occurred in the foliar potassium levels. The potassium level in the young thinning stand at Vesikkosuo had gone down to 0,36 %, which calls for potassium fertilization.

The comparison to the nutrient levels after refertilization reveals that PK refertilization increased the foliar phosphorus and potassium levels in all the experiments (Table 4). The foliar nitrogen level increased with higher nitrogen rates. The foliar magnesium level, compared to other main nutrients, decreased in most instances after the application of high nitrogen rates. A statistically significant negative correlation existed between the foliar nitrogen and the other investigated main nutrient levels. Nitrogen fertilization clearly raised the foliar N/P and N/K ratios (Figs. 1 and 2).

The optimum N/P ratio of pine needles on peatland has, according to Finnish investigations, usually been about 11 (see e.g. Puustjärvi 1962a, 1965, Kaunisto and Paavilainen 1977). Compared to this limit value nitrogen refertilization with 400 kg N/ha or more (with PK fertilizer) resulted in too high N/P ratios. Only in the sample plots of the seedling stand did the foliar N/P ratio stay around limit value 11 or below it even with high nitrogen rates.

The optimum foliar N/K ratio is 3,5 according to Puustjärvi (1962b, 1965). Compared to this the nitrogen application of even 200 kg N/ha raised the foliar nitrogen content too high in many sample plots in relation to potassium amounts.

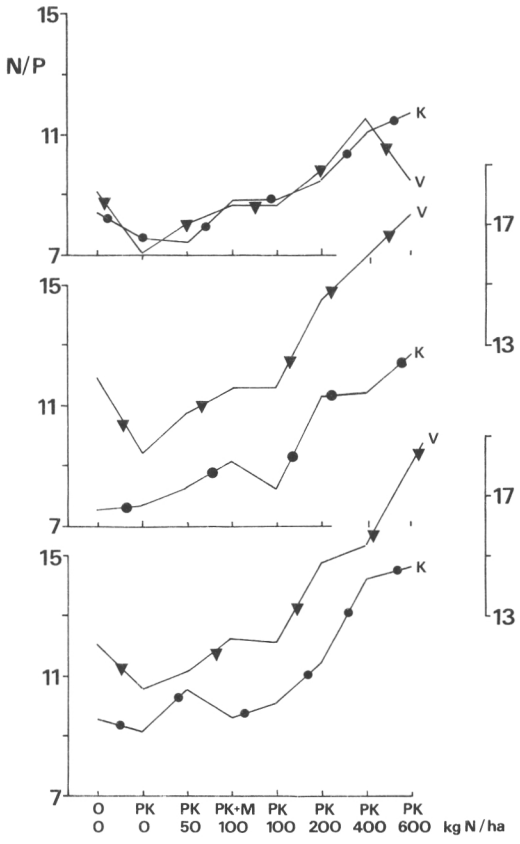


Fig 1. N/P -ratio of the needles two growing seasons after refertilization. K = Köhisevä, V = Vesikkosuo.

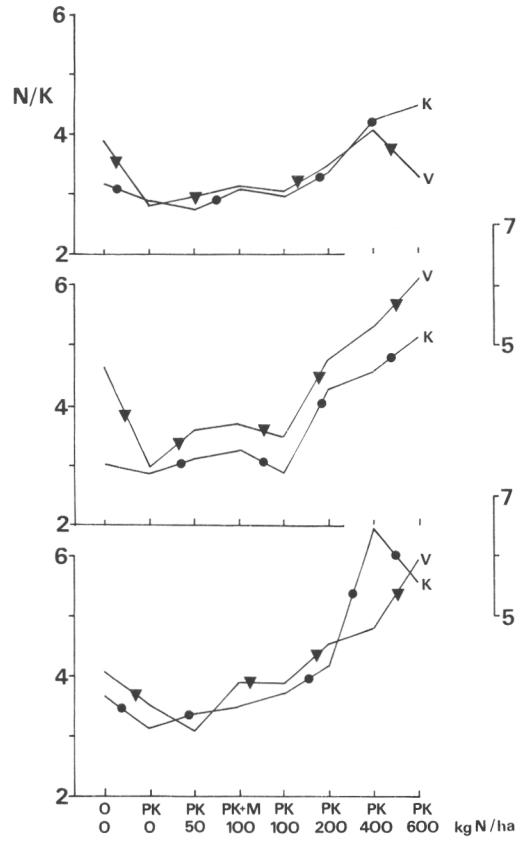


Fig. 2. N/K -ratio on the needles two growing seasons after refertilization. K = Köhisevä, V = Vesikkosuo.

The boron-containing PK fertilizer alone and especially with micronutrients clearly increased the foliar boron content (Table 5). The highest nitrogen doses slightly decreased the average foliar boron level as compared to the sample plots fertilized with mere PK fertilizer or PK with low nitrogen rates.

The micronutrient fertilization did not much affect the foliar copper level (Table 5). The observed difference in the foliar copper level between the experimental fields (the values were higher in the young and old thinning stands at Vesikkosuo than in the other experimental fields) did not level down during these two growing seasons although a copper-containing micronutrient mixture was used. In all the experimental fields at Köhisevä and in the seedling stand at Vesikkosuo the copper levels were below 4 ppm, the lowest being 2,6 ppm, which indicates that these experimental fields may suffer from a copper shortage (see e.g. Kolari 1979, Raitio 1981). The foliar molybdenum level was strongly increased by micronutrient fertilization.

The changes in the foliar nutrient levels after refertilization are clearly shown by the nutrient amounts calculated for a thousand needles (Tables 6 and 7). The amounts also reflect the foliar dry weight increased by fertilization. Thus the total nutrient amounts in needles clearly increased through PK fertilization. Low nitrogen rates (50—100 kg N/ha) further increased the total foliar nutrient amounts. High nitrogen doses did not much contribute to the total nutrient amount, instead it decreased them in some cases.

No distinct correlation between the response to fertilization and foliar nutrient levels by the developmental stage of stands

Table 4. Foliar main nutrient levels two growing seasons after refertilization.

Fertilization			Nutrient content of the needles, per cent of dry weight														
			Köhisevä experimental field														
N	PK-fertilizer	Micronutrient mixture	Seedling stand					Young thinning stand					Old thinning stand				
kg/ha	kg/ha	kg/ha	N	P	K	Ca	Mg	N	P	K	Ca	Mg	N	P	K	Ca	Mg
0	0	0	1,55	0,185	0,489	0,230	0,183	1,33	0,176	0,440	0,226	0,167	1,62	0,170	0,440	0,215	0,181
0	500	0	1,61	0,212	0,556	0,233	0,175	1,64	0,208	0,574	0,219	0,173	1,74	0,190	0,556	0,224	0,154
50	500	0	1,59	0,214	0,579	0,220	0,185	1,67	0,201	0,536	0,209	0,164	1,72	0,163	0,511	0,234	0,161
100	500	0	1,83	0,209	0,607	0,258	0,167	1,65	0,200	0,575	0,186	0,165	1,70	0,168	0,460	0,195	0,182
100	500	100+1,4B	1,86	0,212	0,600	0,234	0,170	1,79	0,195	0,550	0,196	0,153	1,74	0,181	0,497	0,205	0,177
200	500	0	2,02	0,212	0,599	0,260	0,148	2,08	0,184	0,487	0,202	0,151	1,92	0,168	0,461	0,210	0,144
400	500	0	2,15	0,194	0,508	0,229	0,147	2,13	0,186	0,466	0,175	0,156	2,41	0,169	0,373	0,198	0,142
600	500	0	2,30	0,196	0,515	0,231	0,140	2,35	0,185	0,456	0,192	0,157	2,35	0,161	0,423	0,178	0,152
F-value and significance			9,67***	1,90	2,47	1,16	3,35*	20,51***	0,96	5,53**	2,15	1,04	12,39**	10,49**	3,43	1,51	6,80*
Significant difference (5 % risk level)			0,44	—	—	—	0,046	0,37	—	0,116	—	—	0,51	0,017	—	—	0,037
			Vesikkosuo experimental field														
			Seedling stand					Young thinning stand					Old thinning stand				
			N	P	K	Ca	Mg	N	P	K	Ca	Mg	N	P	K	Ca	Mg
0	0	0	1,71	0,189	0,439	0,205	0,175	1,65	0,138	0,357	0,229	0,174	1,63	0,135	0,401	0,220	0,139
0	500	0	1,48	0,208	0,527	0,184	0,161	1,50	0,159	0,507	0,230	0,151	1,79	0,169	0,508	0,227	0,123
50	500	0	1,67	0,208	0,566	0,180	0,189	1,80	0,167	0,500	0,197	0,129	1,72	0,155	0,556	0,208	0,122
100	500	0	1,84	0,211	0,600	0,182	0,171	1,94	0,167	0,556	0,223	0,144	1,86	0,154	0,487	0,217	0,113
100	500	100+1,4B	1,81	0,207	0,577	0,198	0,167	1,95	0,168	0,529	0,202	0,147	1,92	0,156	0,493	0,190	0,105
200	500	0	1,91	0,194	0,550	0,259	0,171	2,36	0,163	0,497	0,182	0,137	2,08	0,141	0,459	0,197	0,109
400	500	0	2,15	0,186	0,530	0,176	0,154	2,40	0,150	0,454	0,167	0,118	2,18	0,142	0,455	0,189	0,115
600	500	0	1,75	0,184	0,530	0,178	0,145	2,67	0,154	0,437	0,172	0,127	2,49	0,138	0,420	0,196	0,124
F-value and significance			2,36	1,34	2,44	2,73	2,85	5,31*	4,16*	4,08*	1,95	4,14*	7,35**	1,86	6,96**	0,70	0,51
Significant difference (5 % risk level)			—	—	—	—	—	1,02	0,029	0,179	—	0,050	0,60	—	0,109	—	—

Table 5. Foliar micronutrient levels two growing seasons after refertilization.

Fertilization			Content of micronutrients in the needles, ppm of dry weight								
			Köhisevä experimental field								
			Seedling stand			Young thinning stand			Old t hinning stand		
N	PK-fertilizer	Micronutrient mixture	B	Cu	Mo	B	Cu	Mo	B	Cu	Mo
kg/ha	kg/ha	kg/ha									
0	0	0	18,7	3,7	0,057	16,7	3,0	0,065	18,0	2,8	0,046
0	500	0	36,0	3,7	0,052	26,0	3,3	0,057	30,0	3,7	0,044
50	500	0	30,7	3,6	0,050	28,7	3,7	0,070	27,0	2,9	0,024
100	500	0	32,3	3,6	0,055	26,7	3,3	0,051	22,5	3,0	0,032
100	500	100 + 1,4B	46,3	3,9	0,353	36,7	3,5	0,168	41,0	3,2	0,074
200	500	0	33,3	3,0	0,064	20,7	3,5	0,052	23,5	3,0	0,037
400	500	0	26,3	3,1	0,067	21,3	2,8	0,048	23,0	2,7	0,024
600	500	0	29,3	3,1	0,026	16,3	3,1	0,062	20,5	2,6	0,031
F-value and significance			5,01**	2,13	19,48***	14,19***	2,55	5,25**	12,11**	3,28	1,46
Significant difference (5 % risk level)			17,7	—	0,120	9,0	—	0,086	12,0	—	—
			Vesikkosuo experimental field								
			Seedling stand			Young thinning stand			Old thinning stand		
			B	Cu	Mo	B	Cu	Mo	B	Cu	Mo
0	0	0	14,5	3,6	0,012	18,5	6,1	0,039	15,0	6,7	0,004
0	0	0	28,5	2,7	0,022	39,0	6,8	0,046	33,5	6,8	0,025
50	500	0	30,0	3,6	0,031	37,5	6,9	0,029	29,5	7,4	...
100	500	0	31,0	3,6	0,036	36,5	7,1	0,010	24,5	6,0	0,102
100	500	100 + 1,4B	40,5	3,3	0,099	55,0	7,8	0,254	44,5	6,7	0,054
200	500	0	33,5	3,8	0,031	29,0	6,5	0,019	28,0	6,9	0,043
400	500	0	26,0	3,9	0,023	32,5	6,1	0,041	26,0	6,3	0,009
600	500	0	25,5	2,8	0,015	25,5	5,4	0,018	22,0	5,6	0,017
F-value and significance			3,82*	0,51	18,15***	15,93***	2,26	6,94	4,27*	2,12	0,81
Significant difference (5 % risk level)			22,2	—	0,038	15,8	—	0,018	24,4	—	—

Table 6. Main nutrient amounts per one thousand needles two growing seasons after refertilization.

Fertilization			Nutrient content of needles, mg/1000 needles														
			Köhisevä experimental field														
N	PK-ferti-lizer	Micro-nutrient mixture	Seedling stand					Young thinning stand					Old thinning stand				
kg/ha	kg/ha	kg/ha	N	P	K	Ca	Mg	N	P	K	Ca	Mg	N	P	K	Ca	Mg
0	0	0	230	28	72	34	27	191	25	63	32	24	212	22	58	28	24
0	500	0	243	32	84	35	26	281	35	98	37	30	298	33	96	39	26
50	500	0	340	46	124	46	39	347	42	111	43	34	332	32	99	45	31
100	500	0	412	46	136	58	37	390	47	135	44	39	322	32	87	37	34
100	500	100+1,4B	455	52	145	57	42	449	50	139	49	38	343	36	98	41	35
200	500	0	524	55	157	68	39	517	48	124	52	38	428	38	102	47	32
400	500	0	614	55	145	65	42	500	45	111	43	38	553	39	86	46	33
600	500	0	595	51	134	60	36	528	42	102	43	35	401	27	72	30	26
F-value and significance			10,25***	5,29**	5,22**	5,75**	2,39	7,76***	1,63	2,47	1,00	1,21	5,40*	3,25	2,30	2,21	3,56*
Significant difference (5 % risk level)			2,27	22	65	27	—	214	—	—	—	—	244	—	—	—	13
			Vesikkosuo experimental field														
			Seedling stand					Young thinning stand					Old thinning stand				
			N	P	K	Ca	Mg	N	P	K	Ca	Mg	N	P	K	Ca	Mg
0	0	0	222	25	57	27	23	184	15	40	25	19	182	15	45	25	16
0	500	0	246	34	87	31	27	195	21	66	30	19	251	23	70	31	17
50	500	0	427	53	145	47	48	338	32	95	38	24	206	19	67	26	15
100	500	0	544	62	179	54	52	358	31	103	41	27	295	25	79	36	18
100	500	100+1,4B	479	55	153	52	44	408	35	111	42	31	278	23	71	28	15
200	500	0	545	55	156	71	48	478	33	99	36	28	320	22	71	31	16
400	500	0	601	51	148	49	43	431	27	82	30	21	289	19	60	25	15
600	500	0	565	60	171	57	47	434	25	72	28	21	360	20	61	29	18
F-value and significance			3,45	3,52*	3,93*	5,79*	2,78	5,70*	5,39*	5,14*	2,42	3,98*	3,91*	0,77	1,46	0,27	0,43
Significant difference (5 % risk level)			—	39	120	33	—	254	16	58	—	12	165	—	—	—	—

Table 7. Micronutrient amounts per one thousand needles two growing seasons after refertilization.

Fertilization			Content of micronutrients in the needles, mg/1000 needles								
			Köhisevä experimental field								
			Seedling stand			Young thinning stand			Old thinning stand		
N	PK-fertilizer	Micronutrient mixture	B	Cu	Mo	B	Cu	Mo	B	Cu	Mo
kg/ha	kg/ha	kg/ha									
0	0	0	278	55	0,94	239	42	0,93	244	37	0,62
0	500	0	542	55	0,78	435	56	0,93	514	63	0,75
50	500	0	651	77	1,94	593	77	1,41	523	56	0,45
100	500	0	724	82	1,22	622	76	1,26	428	56	0,61
100	500	100 + 1,4B	1134	95	8,81	922	88	4,39	818	62	1,48
200	500	0	876	78	1,65	524	89	1,39	517	67	0,84
400	500	0	773	88	1,76	498	66	1,18	528	61	0,54
600	500	0	768	81	0,65	362	69	1,40	352	43	0,53
F-value and significance			3,88*	1,91	8,90***	6,44**	2,38	3,66*	9,97**	2,65	1,51
Significant difference (5 % risk level)			618	—	4,4	392	—	2,9	296	—	—
			Vesikkosuo experimental field								
			Seedlings stand			Young thinning stand			Old thinning stand		
			B	Cu	Mo	B	Cu	Mo	B	Cu	Mo
0	0	0	191	46	0,31	204	68	0,43	172	76	0,09
0	500	0	470	45	0,36	505	89	0,58	473	96	0,37
50	500	0	770	89	0,79	734	133	0,47	375	89	...
100	500	0	867	108	0,99	670	130	0,35	402	99	1,43
100	500	100 + 1,4B	1076	87	2,62	1151	163	5,32	642	98	0,80
200	500	0	912	113	0,82	591	131	0,39	462	107	0,70
400	500	0	718	112	0,63	588	110	1,55	341	82	0,12
600	500	0	834	91	0,47	418	91	0,28	334	81	0,25
F-value and significance			16,83***	0,74	58,96***	8,14**	2,56	11,69**	1,65	0,37	0,77
Significant difference (5 % risk level)			380	—	0,6	537	—	2,8	—	—	—

Table 8. Foliar chlorophyll a and b contents two growing seasons after refertilization.

Fertilization			Chlorophyll contents								
			Köhisevä experimental field								
N	PK-fertilizer	Micronutrient mixture	Seedling stand			Young thinning stand			Old thinning stand		
kg/ha	kg/ha	kg/ha	chl a	chl b	tot	chl a	chl b	tot	chl a	chl b	tot
0	0	0	0,270	0,092	0,362	0,370	0,114	0,484	0,539	0,183	0,722
0	500	0	0,250	0,080	0,330	0,393	0,115	0,508	0,484	0,160	0,644
50	500	0	0,235	0,091	0,326	0,364	0,109	0,473	0,472	0,143	0,615
100	500	0	0,289	0,097	0,386	0,410	0,127	0,537	0,482	0,161	0,643
100	500	100 + 1,4B	0,276	0,087	0,363	0,434	0,130	0,564	0,533	0,180	0,713
200	500	0	0,257	0,085	0,342	0,393	0,120	0,513	0,547	0,175	0,722
400	500	0	0,288	0,098	0,386	0,390	0,115	0,505	0,479	0,156	0,635
600	500	0	0,316	0,115	0,431	0,372	0,108	0,480	0,454	0,142	0,596
			Vesikkosuo experimental field								
			chl a	chl b	tot	chl a	chl b	tot	chl a	chl b	tot
0	0	0	0,281	0,096	0,377	n.d.	n.d.	n.d.	0,360	0,139	0,499
0	500	0	0,284	0,100	0,384				0,360	0,148	0,507
50	500	0	0,303	0,108	0,411				0,364	0,143	0,507
100	500	0	0,450	0,159	0,609				0,412	0,154	0,566
100	500	100 + 1,4B	0,292	0,104	0,396				0,381	0,159	0,540
200	500	0	0,310	0,104	0,414				0,357	0,132	0,489
400	500	0	0,405	0,144	0,549				0,351	0,143	0,493
600	500	0	0,415	0,134	0,549				n.d.	—	—

Table 9. Cell wall thickness in the supportive tissue two growing seasons after refertilization.

Fertilization			Cell wall thickness of supportive tissue μm 1. by the vascular bundle 2. at the center of supportive tissue					
			Köhisevä experimental field					
N	PK-fertilizer	Micronutrient mixture	Seedling stand		Young thinning stand		Old thinning stand	
kg/ha	kg/ha	kg/ha	1	2	1	2	1	2
0	0	0	7,3	6,7	7,0	6,6	7,9	7,7
0	500	0	6,9	5,7	7,7	6,3	8,7	6,8
50	500	0	6,3	6,0	8,1	7,0	8,4	7,2
100	500	0	6,6	5,8	8,1	6,2	8,5	7,4
100	500	100 + 1,4B	6,4	5,5	7,8	6,6	7,7	7,2
200	500	0	6,4	5,5	8,1	5,4	7,9	6,9
400	500	0	6,8	5,4	6,5	5,5	8,2	7,4
600	500	0	6,7	5,5	7,5	5,6	7,6	6,4
			Vesikkosuo experimental field					
			Seedling stand		Young thinning stand		Old thinning stand	
			1	2	1	2	1	2
0	0	0	7,6	7,5	6,5	7,0	5,4	5,9
0	500	0	8,8	7,8	6,2	6,4	6,3	6,2
50	500	0	8,4	6,6	5,2	4,4	5,9	6,1
100	500	0	8,4	7,4	5,5	5,1	7,4	7,3
100	500	100 + 1,4B	8,9	8,4	5,4	5,8	5,8	6,2
200	500	0	8,1	5,7	6,9	7,1	5,8	5,7
400	500	0	8,3	6,9	5,9	5,9	5,8	5,4
600	500	0	8,3	5,6	5,1	5,7	—	—
			4,93	9,73	8,61	2,52	4,19	4,47

Table 10. Cell wall diameter in the supportive tissue two growing seasons after refertilization.

Fertilization			Cell diameter of supportive tissue μm 1. by the vascular bundle 2. at the center of supportive tissue					
			Köhisevä experimental field					
N	PK-fertilizer	Micronutrient mixture	Seedling stand		Young thinning stand		Old thinning stand	
kg/ha	kg/ha	kg/ha	1	2	1	2	1	2
0	0	0	26,0	28,3	20,3	25,0	20,8	23,0
0	500	0	24,4	30,4	21,5	25,6	21,9	23,1
50	500	0	26,1	32,3	21,3	26,8	21,6	24,8
100	500	0	26,1	29,8	22,0	28,1	22,3	25,0
100	500	100 + 1,4B	23,9	28,1	21,2	27,3	20,7	24,0
200	500	0	27,7	30,8	21,8	25,4	21,6	24,5
400	500	0	26,3	29,3	25,1	27,6	20,4	24,1
600	500	0	27,3	30,7	21,4	25,8	20,7	22,1
			Vesikkosuo experimental field					
			1	2	1	2	1	2
0	0	0	20,9	23,8	24,1	25,5	26,6	27,2
0	500	0	23,2	27,2	24,9	28,4	25,0	26,3
50	500	0	22,3	25,7	24,9	27,4	25,9	26,4
100	500	0	21,5	26,4	24,4	26,0	24,3	26,6
100	500	100 + 1,4B	22,7	26,1	25,2	26,8	25,2	26,3
200	500	0	21,3	26,9	23,5	25,9	24,2	25,0
400	500	0	21,1	25,5	25,6	27,8	24,1	24,1
600	500	0	21,3	26,6	24,2	26,1	—	—

was observed. Only the foliar P content slightly decreased with the age of the stand as did the foliar B content. Owing to their greater foliar dry weights some levels calculated per one thousand needles (e.g. nitrogen, phosphorus and potassium) were somewhat higher in seedling stands than in young or old thinning stands.

Chlorophyll contents

There were no significant differences in the foliar chlorophyll contents between the refertilization treatments (Table 8). Thus the chlorophyll content of the needles unexpectedly did not correlate with the foliar nitrogen content. The only two nutrients that had some correlation to the chlorophyll contents were phosphorus and copper. According to the step-wise regression analysis at Köhisevä foliar phosphorus correlated negatively with the content of chlorophyll a ($F = 8{,}04$, $R^2 = 0{,}11$) and chlorophyll b ($F = 19{,}57$, $R^2 = 0{,}24$). At Vesikkosuo there was a positive correlation between foliar copper and chlorophyll b ($F = 7{,}94$, $R^2 = 0{,}11$).

The chlorophyll contents rose somewhat with the age of the stand (Table 8). The highest chlorophyll a/b ratio (3,34) was observed in the young thinning stands.

Needle structure

The needle structure did not reflect the changes in the nutrient contents and ratios due to the refertilization. The cell wall thickness of the supportive tissue was hardly at all dependent on the refertilization treatment (Table 9). Neither was there any clear correlation between refertilization and cell diameter (Table 10). These results differ from those in some earlier studies (e.g. Raitio and Rantala 1977, Raitio 1981), where unbalanced fertilization had clearly affected the needle structure of Scots pine. Possibly the needles of older pine stands studied in this investigation have been more tolerant against heavy fertilization than the needles of pine seedlings studied by the aforementioned authors. Also site types and climatic conditions have been distinctly different in this study compared with the previous ones.

At Köhisevä the cell wall thickness increased but at Vesikkosuo it decreased with the stand age. The cell diameters behaved *vice versa*. The cell diameter was always larger at the center of the supportive tissue than by the vascular bundle as was observed by Raitio (1981).

References

HUIKARI, O. 1974. Hivenravinteet ja puiden kasvu. Metsä ja Puu 11 (1974).

— 1977. Micro-nutrient deficiencies cause growth disturbances. Silva Fenn. 11.3.

— & PAAVILAINEN, E. 1972. Metsänlannoitus. 2. painos. Helsinki.

KAUNISTO, S. & PAAVILAINEN, E. 1977. Response of Scots pine to nitrogen refertilization on oligotrophic peat. Commun. Inst. For. Fenn. 92.1.

KOLARI, K. 1979. Hivenravinteiden puute metsäpuilla ja männyn kasvuhäiriöilmiö Suomessa. Kirjallisuuskatsaus. Abstract: Micro-nutrient deficiency in forest trees and dieback of Scots pine in Finland. A review. Folia For. 389.

MacKINNEY, 1941. Absorption of light by chlorophyll solutions. Biol. Chem. 140: 315—322.

NIEMELÄ, T., PYYKKÖ, M & UOTILA, M. 1974. Mikrotekniikan kurssi. Helsingin yliopiston kasvitieteen laitoksen monisteita 14.

PAARLAHTI, K., REINIKAINEN, A., VEIJALAINEN, H. 1971. Nutritional diagnosis of Scots pine stands by needle and peat analysis. Commun. Inst. For. Fenn. 74.5.

PAAVILAINEN, E. 1974. The use of nitrogen in fertilizing peatland forests. Proc. Intern. Symp. Forest Drainage. Jyväskylä-Oulu, Finland. 1974: 337—345.

— 1977. Jatkolannoitus vähäravinteisilla rämeillä. Ennakkotuloksia. Summary: Refertilization on oligotrophic pine swamps. Preliminary results. Folia For. 327.

— 1978. PK-lannoitus Lapin ojitetuilla rämeillä. Ennakkotuloksia. Summary: PK fertilization on drained pine swamps in Lapland. Preliminary results. Folia For. 343.

— 1979a. Metsänlannoitusopas. Helsinki.

— 1979b. Jatkolannoitus runsastyppisillä rämeillä. Ennakkotuloksia. Summary: Refertilization on nitrogen-rich pine swamps. Preliminary results. Folia For. 414.

PUUSTJÄRVI, V. 1962a. Turpeen typen mobilisoitumisesta ja sen käyttökelpoisuudesta suometsissä neulasanalyysin valossa. Summary: On the mobilization of nitrogen in peat and its usefulness in peatland forests in the light of needle analyses. Suo 13(1).

— 1962b. Suometsien fosforiravitsemuksesta ja neulasten P/N-suhteesta neulasanalyysin valossa. Summary: On the phosphorus nutrition of wet peatland forests and on the P/N ratio in their needles. Suo 13(2).

— 1965. Neulasanalyysi männyn lannoitustarpeen ilmentäjänä. Summary: The analysis of needles as an exponent for the need of fertilization of Scots pine. Metätal. Aikakausilehti 1(1965).
RAITIO, H. 1977. Tallarnas växtstörningar, markens näringsbalans och mikronäringsbrist. Silva Fenn. 11.3.
— 1981. Pääravinnelannoituksen vaikutus männyn neulasten rakenteeseen ja ravinnepitoisuuteen ojitetulla lyhytkorsinevalla. Abstract: Effect of macronutrient fertilization on the structure and nutrient content of pine needles on a drained short sedge bog. Folia For. 456.
— & RANTALA, E-M. 1977. Männyn kasvuhäiriön makro- ja mikroskooppisia oireita. Oireiden kuvaus ja tulkinta. Summary: Macroscopic and microscopic symptoms of a growth disturbance in Scots pine. Description and interpretation. Commun. Inst. For. Fenn. 91.1.
VEIJALAINEN, H. 1975. Kasvuhäiriöistä ja niiden syistä metsäojitusalueilla. Summary: Dieback and fertilization on drained peatlands. Suo 26.5.
WESTMAN, C. J. 1981. Fertility of surface peat in relation to the site type and potential stand growth. Acta For. Fenn. 172.

Total of 21 references

GROWTH DISTURBANCE OF *BETULA PENDULA* IN THE TORAJÄRVI EXPERIMENTAL FIELD

Hannu Raitio

This investigation was carried out in Noormarkku (60°36'N, 21°56'E) in a planted silver birch stand sed up on the alluvial soil over drained Lake Torajärvi. The aim was to describe the growth disturbance symptoms in silver birch (*Betula pendula* Roth) and study the causes leading to growth disturbances by foliar and soil analysis.

Growth disturbances of silver birch are characterized by a bushy crown caused by frequent diebacks. The leaves of bushy and shorter-than-normal and even-aged birches varied in shape and size, being bulgy, cuplike and blistery on undersides. In the late summer of 1979, after a prolonged rainy season, the leaves yellowed gradually and began to display necrosis starting from the edges. The only remarkable symptom discernible by a light microscope was the cavities of spongy cells around leaf veins. In the worst cases trees had died. Till 1979 45 % of the planted birches in the experimental area had died.

The symptoms of growth disturbances as well as foliar and soil analyses support the notion that the disturbances at Torajärvi would have been caused by excessive moisture and manganese toxication induced by the chemical properties peculiar to that soil. The strong invigoration of growth after supplementary drainage confirmed the view that excessive moisture with consequent phenomena had caused the growth disturbances.

Introduction

Growth disturbances characterized by frequent diebacks and disturbances in the apical dominance leading to a bushy growth of trees have been described in pine and spruce. Outwardly resembling disturbances have been discovered also in birch on peatland. One of the reasons for pine and spruce growth disturbances is a shortage of micronutrients, especially boron. The same assumption has been made in the case of birch, although no investigations have been carried out so far.

When Inhottujärvi in Noormarkku (60° 36'N, 21°56'E) was drained in 1960—65, also Torajärvi owned by A. Ahlström Ltd. was included in the drainage. According to the above presented hypothesis a fertilization experiment using micronutrients was set up to cure the growth disturbances discovered in a planted birch stand at Torajärvi. This investigation describes in detail the symptoms found in the area, the effect of fertilization and the water and nutrient conditions that have possibly contributed to the disturbances.

Material and methods

Experimental area

The material was collected from a spacing experiment of Betula pendula set up in spring 1966 in the Torajärvi experimental field (33,8 m a.s.l.) in Noormarkku (60° 36'N, 21°56'E). The area, a former lake bottom, was ploughed using 2,5 m spacings with a Norwegian Plante-Plog plough before planting. Two-year old transplants descending from *Betula pendula* E 210 (Janakkala) through free pollination were planted on the ridges in the spring of 1966. Transplant spacings on the ridges were 1,0 m, 1,5 m, 2,0 m, 2,5 m and 3,0 m. Each spacing treatment was represented by five randomly chosen sample plots, the size of which was 40 × 40 m (Figs. 1 and 2).

A micronutrient fertilization experiment was set up in the area in 1976 to investigate the reasons for growth disturbances and mortality of trees. The experiment was set up on the sample plots of the spacing experiment so that at first two adjacent plots were combined and fertilized either with PK, NPK or left untreated. Within each combined sample plot, there were eight different micronutrient fertilization treatments on 40 m-long strips with four transplant rows. Two untreated (no micronutrients) transplant rows were left between the strips fertilized with micronutrients (Fig. 2). Fertilizers were spread manually on June 15—17, 1976. All the dead trees were removed and counted.

Collection of material

Leaf samples were collected on July 19, 1977, July 16, 1979, and August 6, 1981, from sample plots 7 (0), 8 (NPK) and 9 (PK) as well as from strips with (2) and without (1) micronutrient application (Fig. 2). Eight leaf samples were collected from each treatment so that four samples were randomly chosen from bushy and four from normal birches. A sample consisted of randomly chosen leaves from the upper branches of a birch. The leaves were analyzed for nitrogen, phosphorus, potassium, calcium, iron, boron, copper, zinc and manganese, and in 1979 also for sulphur and in 1981 for sulphur and magnesium at Viljavuuspalvelu Oy (Soil

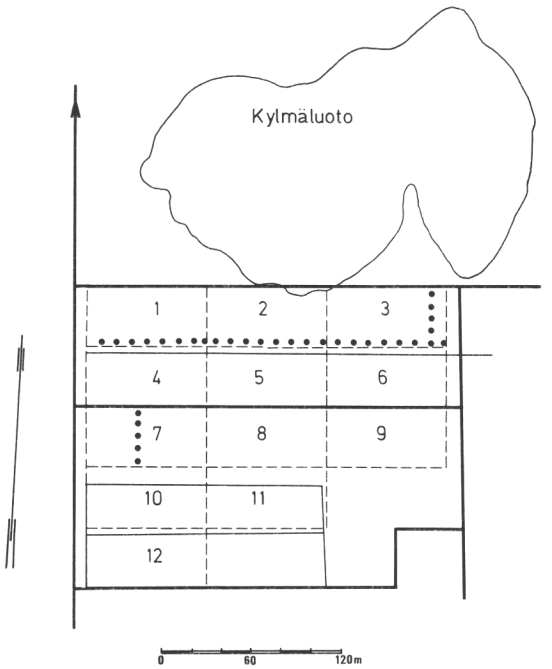
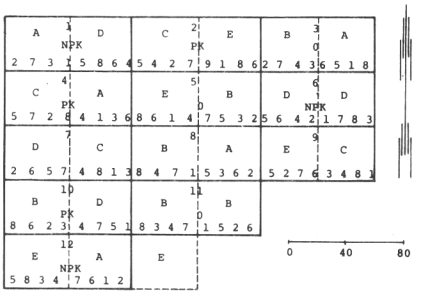


Figure 1. Drain network in a planting density experiment with birch before and after supplementary drainage.



Planting density:

A = seedling spacing 1.0 m
B = seedling spacing 1.5 m
C = seedling spacing 2.0 m
D = seedling spacing 2.5 m
E = seedling spacing 3.0 m

Primary fertilization:

PK, 500 kg/ha of granular PK for peatland forests
NPK, 350 kg/ha of Oulu salpetre and
500 kg/ha granular PK for peatland forests

Micronutrient fertilization:

1. 0
2. Micronutrient, 100 kg/ha micronutrient mixture
3. B, 20 kg/ha natrium polyborate
4. Cu, 20 kg/ha copper sulphate
5. B + Cu
6. B + Cu + Zn, in which Zn = 30 kg/ha zinc sulphate
7. B + Cu + Mn, in which Mn = 25 kg/ha manganous sulphate
8. B + Cu + Zn + Mn

Applied fertilizers:

Granular PK for peatland forests 0-19-19, Mg 0.7, B 0.2
Oulu salpetre 27,5 N, Mg 0.2
Natrium polyborate 0.2 B
Copper sulphate 25.0 Cu
Zinc sulphate 23.0 Zn
Manganese sulphate 26.0 Mn
Micronutrient mixture: 1.1, Cu 12.8, Mn 5.5, Zn 5.5, Fe 9.6 (as carbonate) Fe 0.2 (as chelate), Mo 1.4 and Na 0.7

Figure 2. Fertilization treatments of the planting density experiment with silver birch.

Testing Service Co.). The annual differences in nutrient levels were tested with a single classification variance analysis and Tukey's test (w-procedure).

Soil samples (86) consisting of five randomly chosen subsamples (4 cm × 5 cm × 10 cm) were collected on June 20 and August 17, 1979, from the depths of 0—10 cm and 10—20 cm on plot 7, on the strip without micronutrient application. The samples were analyzed for total nitrogen, soluble phosphorus, exchangeable potassium, exchangeable calcium, water-soluble boron, exchangeable manganese, acid-soluble copper, zinc, iron and aluminum as well as pH from water extract at Viljavuuspalvelu Oy. Furthermore, the soil particle structure was determined from a soil sample taken by the method described above from the depths of 5—15 cm and 15—25 cm. The sampling depth differed in the latter case, as the surface soil layer, 0—5 cm, was purely organic.

At the 1979 sampling, eight leaf and soil samples were collected for the control from a birch stand planted on an old fertile mineral field in the spring of 1970, using the same collection method as previously. The birch stand was situated in Santapelto, about 2,5 km south-west of the spacing experiment at Torajärvi.

The depth of the ground water table was measured at the spacing experiment every week from September 18 to December 31, 1978, and from May 1 to December 8, 1979, from 33 ground water wells, whose locations are shown by Figure 1.

The effect of the depth of the ground water table on the redox potential was measured in laboratory conditions. The depth of the ground water table in the investigated soil profiles, whose height was 35 cm and diameter 10 cm, was regulated by a method described by Juusela et al. (1969). The soil profiles were taken from plot 7, on the strip untreated with micronutrients, on November 3, 1981. The experiment was set up on November 6 and the redox measurements started on November 9, 1981. The ground water table was at 0, 10, 20 and 30 cm. Each treatment was replicated three times. Acidity and redox potential were directly measured from the 0—5 cm layer with the Beckman Chem-mate pH gauge using a combine electrode (Beckman 39508). The measurement period was on November 9—20, 1981.

The mean height of each tree on the strips with four different micronutrient treatments (0, B, Hi = a micronutrient mixture, B + Cu + Zn) was measured on July 16—24, 1979. At the same time the number of dead trees was recorded. Supplementary drainage was carried out in the experimental area and the old ditches were cleaned on June 1 — July 7, 1980 (Fig. 1).

Results

A 250-ha area exposed after drainage at Torajärvi is of heavy clay, the 5—25 cm top layer being acid, plenty of sulphur and manganese containing gyttja. As a former field the control area is nutritious fine sand (Table 1). As a result of drainage the gyttja clay at Torajärvi has cracked badly, thus promoting the drying of soil similarly to underdrainage. This is probably the reason for sudden variations in the ground water table. In 1979 the ground water table was at the depth of 25 cm on average. The ground water table was deeper in the area with healthy stands than in the area of bushy or dead trees. The area was also occasionally flooded.

The growth disturbance in birch was characterized by a bushy crown caused by frequent diebacks. The leaves of bushy, shorter-than-normal birches varied in shape and size being bulgy, cuplike and blistery on undersides. In the late summer of 1979, after a prolonged rainy season, the leaves yellowed gradually and began to display necrosis starting from the edges. The only

Table 1. Soil nutrient contents and pH at different dates at Torajärvi and Santapelto.

		Investigated area							
		Torajärvi				Santapelto			
		Sampling date							
		20.6.1979		17.8.1979		30.6.1979		17.8.1979	
		Sampling depth							
		0—10	10—20	0—10	10—20	0—10	10—20	0—10	10—20
$pH_{(H_2O)}$		4,3	4,4	4,7	4,6	7,1	7,0	6,6	6,6
N tot	%	0,7	0,6			0,5	0,4		
P sol.	mg/l	2,7	3,0			4,4	3,4		
K exch.	mg/l	29	36			209	160		
Ca exch.	mg/l	70	188			5300	4600		
B water-sol.	mg/l	0,15	0,20	0,25	0,28	0,4	0,3	0,3	0,3
Cu acid-sol.	mg/l	2,3	3,6			7,0	8,1		
Zn acid-sol.	mg/l	13,8	13,3			50,0	50,0		
Mn exch.	mg/l	7,1	23,3	36,6	76,8	1,4	1,4	3,9	3,2
S easily-sol.	mg/l	42,5	23,1	7,3	17,2	4,8	4,9	4,2	5,6
Fe acid-sol.	g/l	2,5	4,5	3,4	4,0	5,0	5,4	3,7	4,2
Al acid-sol.	g/l			7,0	5,5			8,7	8,7

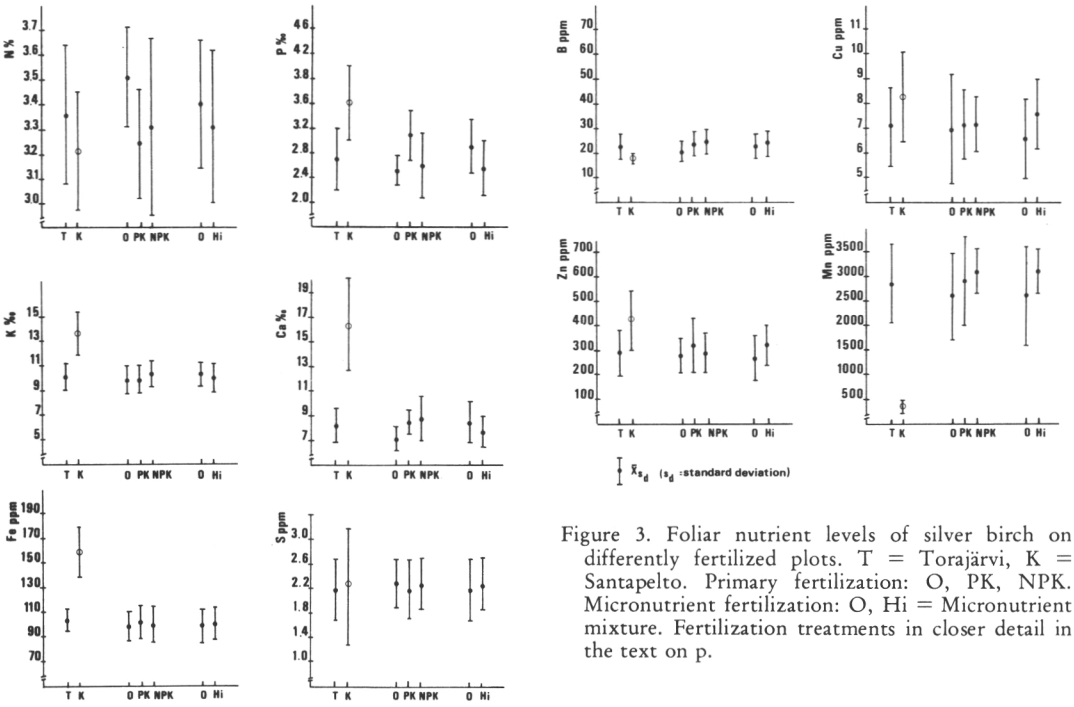


Figure 3. Foliar nutrient levels of silver birch on differently fertilized plots. T = Torajärvi, K = Santapelto. Primary fertilization: O, PK, NPK. Micronutrient fertilization: O, Hi = Micronutrient mixture. Fertilization treatments in closer detail in the text on p.

Table 2. Foliar nutrient levels of healthy and injured silver birches on 16 July, 1979.

Degree of injury	N %	P %	K %	Ca %	S %	Fe ppm	B ppm	Cu ppm	Zn ppm	Mn ppm
Healthy (control area)[1)]	3,21	3,57	13,5	16,4	2,26	151	17,5	7,2	419	340
Healthy-looking[2)]	3,70	2,65	10,5	8,4	2,30	77	21,4	5,9	210	532
Mild injury[2)]	3,39	3,30	10,5	9,2	2,29	103	18,8	7,7	174	1648
Severe injury[2)]	3,70	2,93	10,3	11,7	2,29	124	36,0	9,4	442	3587

1) Average of eight samples
2) One sample

remarkable symptom discernible by a light microscope was cavities in spongy cells around leaf veins. In the worst cases the entire tree had died. Out of all the trees in the area 45 % had died till 1979.

The average height of silver birch at Torajärvi was 2,58 m in 1970, 5,15 m in 1977 and 6,28 m in 1979. The average height of trees in the control area was 10,7 m in 1979.

Birch leaves at Torajärvi contained slightly more nitrogen and boron and considerably more manganese than in the control area. The situation was contrary in case of other nutrients excluding sulphur, whose levels were the same on the average in both areas (Fig. 3). Fertilization with PK, NPK and a micronutrient mixture had no effect on the foliar nutrient levels (Fig. 3). After the supplementary drainage in 1981 the nitrogen, potassium, calcium, iron, copper, zinc, sulphur and manganese levels were lower than before the drainage. On the other hand, boron levels were higher than in 1979 and no statistical differences in phosphorus contents were found between the years (Fig. 4).

As the injuries became severer, the foliar manganese level increased suddenly. There were slightly more nitrogen and boron, but less phosphorus, potassium, calcium and iron in the leaves of injured trees as compared to the control area (Table 2). These nutrient levels did not, however, reflect as systematically as manganese the severity of growth disturbances. One must, however, note that only very few samples were involved, just one sample/disturbance degree apart from the control.

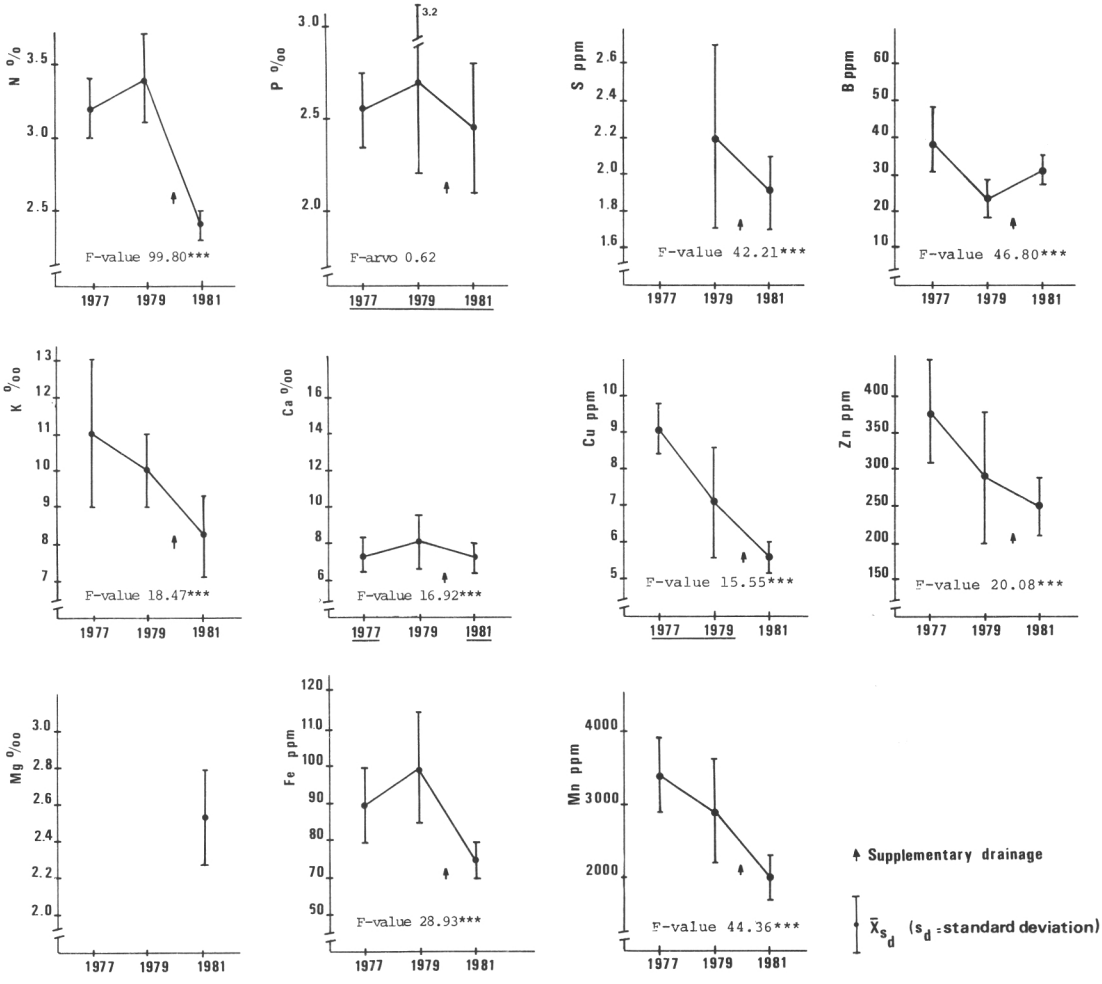


Figure 4. Foliar nutrient levels of silver birch at Torajärvi in different years. F values and significances from the analyses of variance and Tukey test results.

Discussion

As a former lake bottom, the physical features of the soil in the investigation area were characterized by gyttja or gyttja clay (see Soveri 1964, Stålfelt 1969). Both soil types are characterized by shrinking and cracking during a dry season but expansion when wet. This is a possible explanation for the fact that the soil at Torajärvi had badly cracked after drainage. In comparison to the soil analyses of the control area and analysis results obtained by Kurki (1972) from gyttja and gyttja clay on fields, the soil at Torajärvi contained extremely low amounts of potassium, phosphorus and calcium. Similarly, there were only little boron, copper and zinc, but high amounts of sulphur and manganese. The laboratory experiment suggested that at least occasionally also reduced circumstances prevail at Torajärvi at all the investigated depths of ground water table (see Starkey & Wight 1945, Brown et al. 1966, Scheffer & Schachtschabel 1976, Eurola & Kaakinen 1978), which is also implied by the smell of hydrogen sulphide in summer 1979 (see Amberger 1979).

In acid, reduced conditions the soil sulphur (SO_4^{2-}) is reduced to hydrogen sulphide (H_2S) and iron sulphides (FeS, FeS_2) toxic to plants. Similarly, iron (Fe^{3+}), manganese (Mn^{4+}, Mn^{3+}) and aluminum (Al^{3+}) are reduced to a form available to plants (Amberger 1979) likely to cause toxi-

cation. In such conditions nitrogen is characterized by denitrification and phosphorus by fixation to poorly soluble iron and aluminum phosphates (Amberger 1979, Mengel & Kirkby 1979). It is possible, especially in rainy summers when the ground water table has been high at Torajärvi, that birches have suffered, above all, from excessive amounts of manganese and possibly from hydrogen sulphide and other toxic compounds brought on by anaerobic conditions.

The symptoms and foliar analyses support the assumption that the growth disturbances at Torajärvi have mainly been caused by a manganese toxication. The symptoms of manganese toxication are seen in the shoots rather than roots (Hiatt & Ragland 1963). At its initial stages toxication is characterized by disturbances in the chlorophyll synthesis, which leads to chlorosis at first about the leaf veins of older leaves and later between the veins. Later as the excessive manganese in the plant gradually becomes oxidized to manganese dioxide (MnO_2) the tissue at the tips and edges of leaves start browning and showing necrosis. Finally the leaves die. The leaves are variously shaped, wrinkled and with rolled edges. As the situation grows worse, not only the leaves but also the terminal buds and older roots die. However, because of the lateral buds new shoot and root branches grow, although they may also die depending on the situation. This is the reason for the bushy form seen at Torajärvi. In the worst case the entire tree individual dies (Burghardt 1956, Williams & Vlamis 1957, Bussler 1958, Roorda van Eysinga & Smilde 1971, Hoyle 1972, Bergmann & Neubert 1976, Le Mare 1977 a).

The symptoms of manganese toxication are not typical. The toxicity is to be confirmed by nutrient analyses, by comparing individuals with and without symptoms (Solbraa & Selmer-Olsen 1981). Yet, it is difficult to verify the manganese toxication even analytically for the following reasons:

1. The manganese tolerance of plants varies with age and species (Roorda van Eysinga & Smilde 1971).
2. The manganese tolerance of plants depends on the calcium, phosphorus and silicon conditions (Williams & Vlamis 1957, Le Mare 1977 a and b, Horst & Marschner 1978).
3. The soil manganese will become available to plants in acid, anaerobic conditions. Then also other compounds toxic to plants such as hydrogen sulphide, carbon dioxide and various organic acids start forming.

The high foliar manganese levels at Torajärvi are caused by the chemical properties of the soil and excessive wetness. Despite the rainy summer, the foliar manganese levels decreased as a result of the supplementary drainage and cleaning of old ditches. The effect of drainage was also visible in the growth of birch and size of leaves. The implication is that excessive wetness with consequent phenomena causes growth disturbances.

According to Huikari (1955, 1959) silver birch is fairly tolerant of anaerobic conditions. On the other hand, Raulo (1981) claims that silver birch does not usually grow on moist or low-oxygen substrates. The present investigation suggests that the ability of a tree species to endure anaerobic conditions also depends on the chemical properties of the soil.

As the main nutrients were in balance and partly because of the anaerobic conditions, the application of macro- and micronutrients did not affect the mean height of the stand or the foliar nutrient levels. Viro (1974) has stated that in pure birch stands the ground vegetation has probably consumed a remarkable part of the existing nutrients. Thus the effect of fertilization is short and rather modest, an average of three years, in pure stands.

The investigations have confirmed that a shortage of micronutrients, primarily boron, is one of the causes for growth disturbances in conifers (Raitio 1979, 1981, Silfverberg 1980, Veijalainen 1981). The growth disturbances in this investigation do not seem to be caused by a micronutrient shortage but excessive wetness with consequent phenomena. The macroscopic symptoms of growth disturbances encountered in silver birch are very similar to those found in white birch on peatlands.

Literature

AMBERGER, A. 1979. Pflanzenernährung. 237 s. Stuttgart. Eugen Ulmer GmbH & Co.

BERGMANN, W. & NEUBERT, P. 1976. Pflanzendiagnose und Pflanzenanalyse zur Ermittlung von

Ernährungsstörungen und des Ernährungszustandes der Kulturpflanzen. 711 s. Jena. Gustav Fischer Verlag.
BROWN, A.H.R., CARLISLE, A. & WHITE, E.J. 1966. Some aspects of the nutrition of Scots pine on peat. Forestry 35: 78—87.
BURGHARDT, H. 1956. Beiträge zum Eisen-Mangan-Antagonismus der Pflanzen. Flora 143: 1—30.
BUSSLER, W. 1958. Manganvergiftung bei höheren Pflanzen. . PflErnähr. Bodenk. 81.3: 256—265.
EUROLA, S. & KAAKINEN, E. 1978. Suotyyppiopas. 87 s. Porvoo—Helsinki—Juva. WSOY.
HIATT, A.J. & RAGLAND, J.L. 1963. Manganese toxicity of burley tobacco. Agron. J. 55: 47—49.
HORST, W.J. & MARSCHNER, H. 1978. Effect of silicon on manganese tolerance of bean plants (Phaseolus vulgaris L.) Plant and Soil 50: 287—303.
HOYLE, M.C. 1972. Manganese toxicity in yellow birch (Betula alleghaniensis Britton) seedlings. Plant and Soil 36: 229—232.
HUIKARI, O. 1955. Experiments on the effect of anaerobic media upon birch, pine and spruce seedlings. Seloste: Kokeita kasvualustan anaerobisuuden vaikutuksesta koivun, männyn ja kuusen taimiin. Commun. Inst. For. Fenn. 42 (5): 1—13.
— 1959. On the effect of anaerobic media upon the roots of birch, pine and spruce seedlings. Seloste: Kasvualustan anaerobisuuden vaikutuksesta koivun, männyn ja kuusien taimien juuristoihin. Commun. Inst. For. Fenn. 50 (9): 1—14.
KURKI, M. 1972. Suomen peltojen viljavuudesta II. 182 s. Viljavuuspalvelu Oy.
LeMARE, P.H. 1977a. Experiments on effects of phosphorus on the manganese nutrition of plants. II. Interactions of phosphorus calcium and manganese in cotton crown with nutrient solutions. Plant and Soil 47: 607—620.
— 1977b. Experiments on effects of phosphorus on the manganese nutrition of plants. III. The effect of calcium: phosphorus ratio on manganese in cotton grown in Buganda soil. Plant and Soil 47: 621—630.
MENGEL, K. & KIRKBY, E.A. 1979. Principles of plant nutrition. 593 s. Bern. International Potash Institute.
RAITIO, H. 1979. Boorin puutteesta aiheutuva männyn kasvuhäiriö metsitetyllä suopellolla. Oireiden kuvaus ja tulkinta. Abstract: Growth disturbances of Scots pine caused by boron deficiency on an afforested abandoned peatland field. Description and interpretation of symptoms. Folia For. 412: 1—16.
— 1981. Pääravinnelannoituksen vaikutus männyn neulasten rakenteeseen ja ravinnepitoisuuksiin ojitetulla lyhytkorsinevalla. Abstract: Effect of macronutrient fertilization on the structure and nutrient content of pine needles on a drained short sedge bog. Folia For. 456: 1—10.
RAULO, J. 1981. Koivukirja. 131 s. Jyväskylä. Gummerus.
ROORDA VAN EYSINGA, J.P.N.L. & SMILDE, K.W. 1971. Nutritional disorders in glasshouse lettuce. 56 s. Wageningen.
SCHEFFER, F. & SCHACHTSCHABEL, P. 1976. Lehrbuch der Bodenkunde. 394 s. Stuttgart. Ferdinand Enke Verlag.
SILFVERBERG, K. 1980. Kuusen kasvuhäiriö ja hivenravinteet. Abstract: Micronutritional growth disorder in Norway spruce. Folia For. 432: 1—13.
SOLBRAA, K. & SELMER-OLSEN, A.R. 1981. Manganese toxicity — in particular when growing plants in bark compost. Causes, symptoms, exctraction methods and precautions. Acta Agr. Scandinavica 31: 29—39.
SOVERI, U. 1964. Maalajit ja niiden käyttö. Teoksessa RANKAMA, K. 1964. Suomen geologia 414 s. Helsinki. Kirjayhtymä.
STARKEY, R.L. & WIGHT, K.M. 1945. Anaerobic corrosion of iron in soil. Final report of the American gas Association iron corrosion research fellowship. New York.
STÅLFELT, M.G. 1969. Växtekologi. 443 s. Stockholm. Kungl. Boktryckeriet P.A. Notdstedt & Söner.
VEIJALAINEN, H. 1981. Hivenlannoituksen vaikutus istutusmännikön kehitykseen turvemaalla. Summary: Long-term responses of Scots pine to micronutrient fertilization on acid peat soil. Folia For. 477: 1—15.
VIRO, P.J. 1974. Fertilization of birch. Seloste: Koivun lannoitus. Commun. Inst. For. Fenn. 81 (4): 1—38.
WILLIAMS, D.E. & VLAMIS, J. 1957. The effect of silicon on yield and manganese -54 uptake and distribution in the leaves of barley plants grown in culture solutions. Plant physiol. 32: 404—409.

Total of 28 references

VARIATION OF BORON CONCENTRATION IN PINE NEEDLES FROM TREES GROWING ON MINERAL SOIL IN SWEDEN AND RESPONSE TO NITROGEN FERTILIZATION

Göran Möller

The paper gives a short description of the first observations of growth disturbances from boron deficiency on mineral soils i Sweden. It shortly describes the results from a pilot study in 1979/80 where the reason for earlier observed growth disturbances in refertilized trials and operationally refertilized stands are shown to be the effect of induced boron deficiency. It also gives the result from an investigation in 1980/81 where the natural boron concentration in the needles is shown to be extremely low in the northernmost region of Sweden and increase towards the south in the same rate as the boron concentration in lake and stream water.

Growth disturbances on Scots pine and Norway spruce growing on peat soils have been observed rather long time in Scandinavia. Most often these disturbances have occurred on drained and fertilized sites. From the beginning these disturbances were considered to be caused by frost damages but at the end of the 1960's the scientists became more and more convinced that the disturbances were caused by deficiency of some micro-nutrient. In the beginning of the seventies it also was shown that at least in some cases these growth disturbances were caused by boron deficiency. That disturbance gave the trees a bushy appearance by repeated killing of the leading shoot.

On mineral soils, however, no such disturbances had been observed so far, not even after very heavy nitrogen applications up to 600 kilos of pure nitrogen per hectar. First at the dose of 840 kg N/ha in one single application growth disturbances and toxic effect had been observed (Fig. 1).

In 1969 professor C.O. Tamm at the Swedish University of Agricultural Sciences observed some curious defects in three fertilization trials established in 1959. These trials included treatments with both NPK and calcium in different combinations. The nitrogen was given at a dose of 60 kg N/ha every second year, while the other elements were given only at time for establishment and at the doses of 43 kg P, 100 kg K and 4.000 kg of calcium. After ten years, in 1969, a number of dead tops were observed in some plots and the number of these dead tops in 2 of the different treatments are given in Table 1. At the same time an unusual amount of droppings from wood-grouse birds was observed on some plots and an investigation showed a good correlation between number of dead tops and amount of droppings in the plot. From that investigation the conclusion was drawn, that the browsing from wood-grouse caused the

Table 1. Number of dead tops in 1969 in three of prof. C.O. Tamms fertilization trials from 1959. (Personal communication)

Trial	Treatment		
	Control	N	NPKCa
Lövnäs 731	—	2	7
Bleckstugan 731A	—	2	49
Häggsjöliden	—	1	28

Doses applied: N 60 kg/ha in 1959, -61, -63, -65, -67
P 43 kg/ha in 1959
K 100 kg/ha in 1959
Ca 4000 kg/ha in 1959



Figure 1. At 840 kg N · ha^{-1}, given as ammonium nitrate in one single application, the trees started to die. Trial D 182 Vestinska torpet.
Photo G. Möller 1971.

top-dying. It was hard to understand why these birds should choose trees only from some of the fertilized plots, so there still were some doubts about the real reason for the top-dying.

In the mid seventies dr Aron Aronsson at the same department as professor Tamm showed in his freeze-tests investigations in an other trial with growth disturbances that needles from both limed and nitrogen fertilized plots had a very high nitrogen concentration, between 2—3 per cent, while at the same time the boron concentration was between 1.5—4 ppm only. This gave the first indication that the former observed growth disturbances on mineral soil initially were caused by boron deficiency and that the wood-grouse birds were drawn to certain plots by the extremely high nitrogen concentration in the needles.

At this time in the middle of the seventies, there also came some reports on dead top-shoots and dying tops in our own refertilized trials. Also dying tops in operationally re-fertilized stands in northern Sweden were reported, but all reports, however, came from the northern part of Sweden.

During the autumn and winter of 1979/80 we therefore decided to perform a pilot-study to look upon the boron and nitrogen concentration in needles from all of our own trials re-fertilized with nitrogen three growing seasons before, that means re-fertilized in 1977.

The results of this study are summarized in Table 2. By studying the boron concentra-

Table 2. Nitrogen and boron concentration in the 1979 needles from plots on mineral soil refertilized in 1977 with different amounts and sources of N.

Trial		Lat.	Control		Source	Dose of N kg · ha^{-1} 120		240		480	
	S = spruce P = pine		N %	B ppm	of N	N %	B ppm	N %	B ppm	N %	B ppm
1 Vuollerim	P	66°20′	1,12	7,2	AN	1,25	3,9	1,41	3,4	—	—
D98 Moskosel	P	65°50′	1,13	7,6	Urea	1,24	6,0	1,38	1,9	1,65,	1,7
					AN	1,27	2,7	—	—	—	—
G38 Tsåkasliden	P	65°40′	0,94	9,9	AN	1,27	4,3	—	—	—	—
2 Sunderbyn	P	65°40′	1,17	8,5	AN	1,28	8,9	1,35	8,6	—	—
D194 Sandbacksmon	P	63°30′	1,28	6,5	Urea	1,51	3,7	—	—	—	—
D157 Bomsund	P	63°05′	1,02	9,9	Urea	1,19	6,4	1,22	6,3	—	—
Average north of 60°			1,11	8,3		1,29	5,1	1,34	5,1	1,65	1,7
D11 Mangskog	S	59°50′	1,31	15,7	Urea	1,37	9,0	1,32	6,3	1,42	6,2
8 Össebygarn	P	59°50′	1,20	13,8	AN	1,30	15,1	1,49	10,9	—	—
71 Forssjöbruk	P	59°00′	1,14	14,9	AN	1,39	10,5	—	—	—	—
Average south of 60°			1,22	14,8		1,35	11,5	1,41	8,6	1,42	6,2

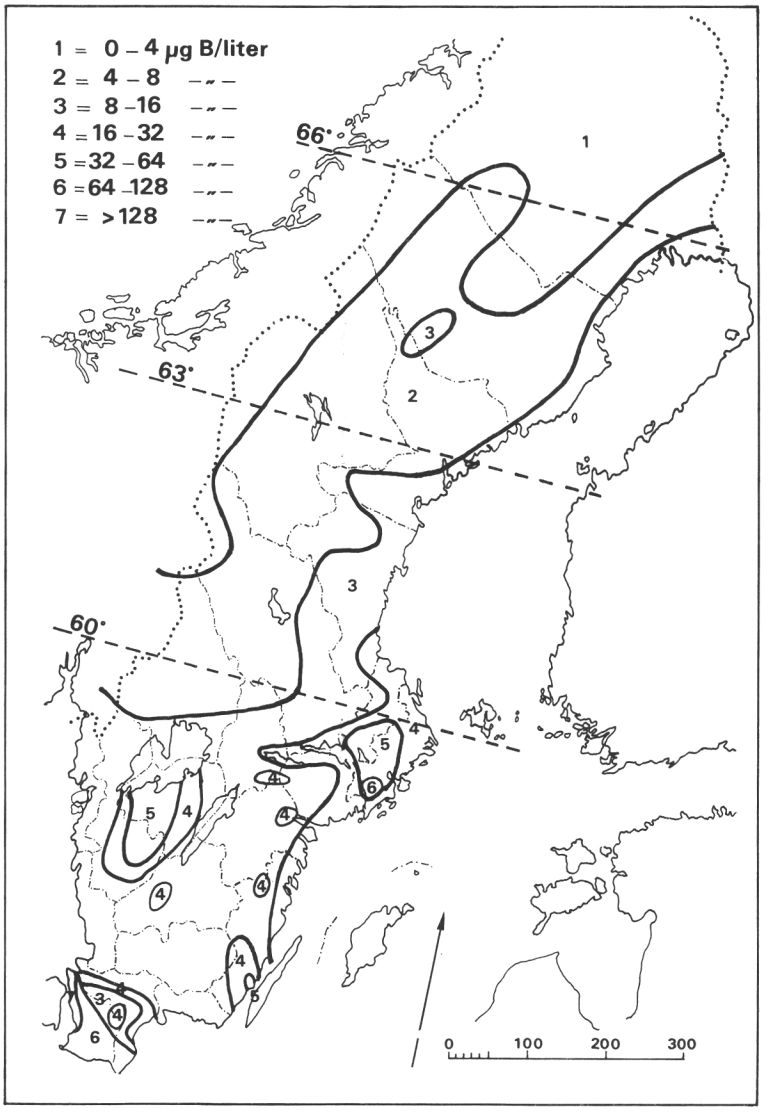


Figure 2. Boron zones for Swedish fresh waters after Th. Ahl and E. Jönssön 1972.

tion in the control plots we can first see how the boron concentration in the needles varies between 6.5—9.9 ppm north of latitude 60° but increases to 13.8—15.7 ppm when we go south of 60° latitude. We can also see how the nitrogen fertilization decreases the boron concentration in the needles at the same time as the nitrogen concentration increases. There are some exceptions, however, e.g. in trial no. 2 Sunderbyn. At time for needle-sampling no growth disturbances were observed in this trial but 1981 and this year rather severe disturbances have been observed. In the other trials, where the nitrogen fertilization had decreased the boron concentration down to 4 ppm of less, growth disturbances were observed in some of the plots. But also here there were some exceptions, e.g. in trial D 98 Moskosel, where the application of 240 kg N as urea had decreased the boron concentration down to 1.9 ppm but no disturbances were to be seen at time for sampling. In treatment 480 kg N/ha, on the other hand, where the boron concentration had dropped to 1.7 ppm and nitrogen concentration had jumped up to 1.65 per cent, severe disturbances could be seen at

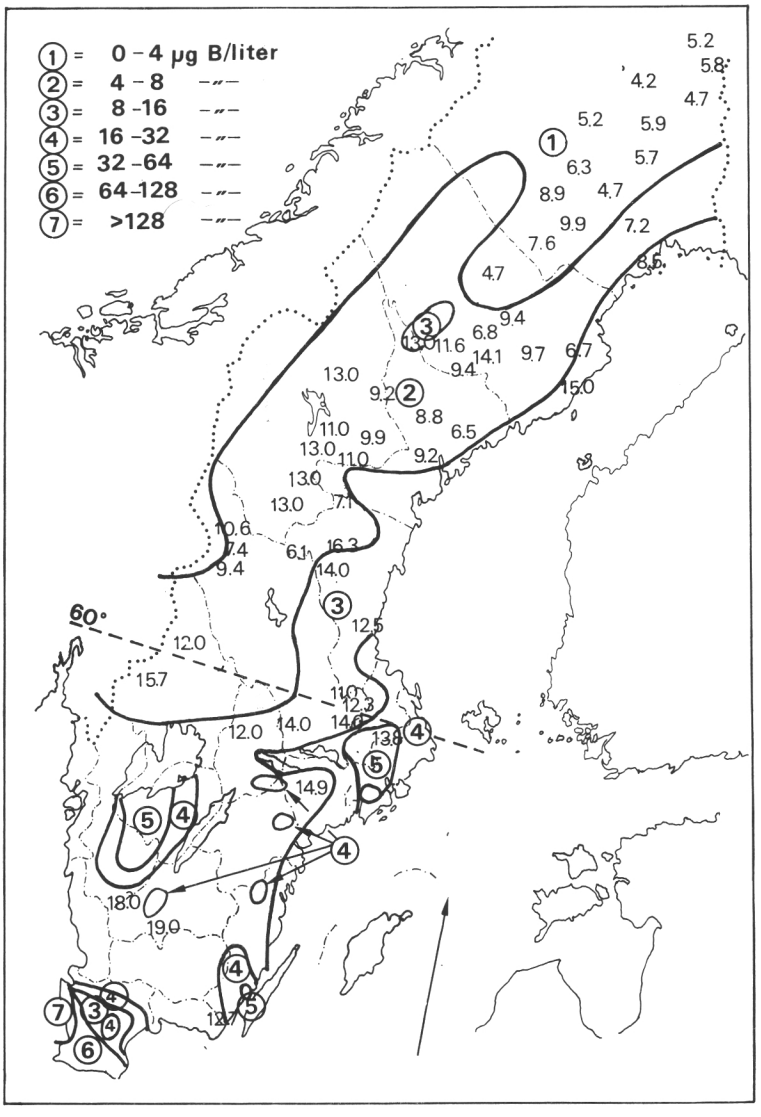


Figure 3. Boron concentration (ppm) in needles from different places, and regions with different boron concentration in lake water.

the time of sampling.

The big natural variation in needle boron concentration from different places, as found in this pilot study, made it important to investigate in which regions of the country this very low natural boron concentration is to be found and subsequently where we will have big risks for growth disturbances after operational fertilizations. In 1972 Th. Ahl and E. Jönsson investigated the boron concentration in Swedish and Norwegian fresh waters. They found that there was a big variation between different regions and they also draw a map (Fig. 2), showing zones with different concentration of boron in the water. It was then reasonably to assume that the needle boron concentration could show the same pattern and therefore we decided to perform a new investigation during the winter of 1980/81 to see how this assumption fitted with the reality. We collected needle samples from roughly 50 different untreated stands spread all over the country but with a concentration towards the northern part where growth disturbances had been found earlier.



Figure 4. Typical symptoms of induced boron deficiency on mineral soil.
Photo G. Möller.

The result of this investigation is shown in figure 3 where the boron concentration in needles from different places are given together with the different zones for boron in fresh water as found by Ahl and Jönsson. From this picture it comes out rather clearly, that there is a conection between the different zones for boron in the water and the natural boron concentration in the needles, even if there are some exceptions. The net of samples has been tightened during the last winter, but the figures are not available yet.

When we know that a nitrogen fertilization with 150 kg/ha will decrease the boron concentration in the needles with 4—5 ppm, it is quite obvious that the risks for growth disturbances are rather high north of roughly 60° latitude and extremely high in the inland of northern Sweden. And that I think we can say even if we not yet exactly know the critical point for boron concentration, when disturbances will occur.

These disturbances after a nitrogen fertilization on mineral soil are probably only temporary for a couple of years and therefore they normally show a little different picture then those on peat soils, where the deficiency probably is more or less chronic after a PK fertilization. Figure 4 shows typical symptoms of induced boron deficiency on mineral soil. As we can see the bushy appearance is not so pronounced as normally could be expected, but the leader will die for one or two years until the biomass has been reduced enough for adequate supply of boron from the soil and the whole crown will give a very thin appearance in regard to the thick, dark green crown that normally is related to the treatment.

In order to prevent these growth disturbances in operational fertilizations, it is now recommended to add 1 kg boron per hectar together with the nitrogen, when fertilizing north of latitude 60°. If that dose is big enough to prevent disturbances in all places and for all nitrogen doses is still left to be proved, as well as to determine how long the effect of such a small dose will last.

Literature

AHL, TH. & JÖNSSON, E. 1972. Boron in Swedish and Norwegian Fresh Waters, Ambio 1 (2): 66—70.

ARONSSON, A. 1980. Frost hardiness in Scots pine II. Hardening during winter and spring in young trees of different mineral status. Stud. For. Suec. 155: 1—27.

BURGTORF, H. 1981. The effects of supply of plant nutrients to some pine stands on poor and cold sites. Swed. Univ. of Agr. Sciences, Reports in Forest Ecology and Forest Soils 37: 1—34.

KOLARI, K. K. 1979. Hivenravinteiden puute metsäpuilla ja männyn kasvuhäiriö Suomessa. Kirjallisuuskatsaus. Abstract: Micro-nutrient deficiency in forest trees and dieback of Scots pine in Finland. A review. Folia For. 389: 1—37.

Total of 4 references

GROWTH DISTURBANCES CAUSED BY BORON DEFICIENCY IN SOME FERTILIZED PINE AND SPRUCE STANDS ON MINERAL SOILS

Aron Aronsson

In some of the fertilization experiments managed by the Section of Forest Ecology (Swedish University of Agricultural Sciences), growth disturbances occurred after several years of fertilization. The injury symptoms and the low B content in current needles indicate that B deficiency is the damaging factor. There is a significant decrease in B content of needles with increased N-fertilization. There seems to be a limit at about 4—5 $\mu g \cdot g^{-1}$ in needles above which injury is unusual and below which further lowering of B content will increase the risk of damage. This risk will be further increased if N-fertilization is combined with liming.

One experiment involved both irrigation and fertilization treatments, where all essential macro- and micronutrients were applied in proportions which had given optimal growth of seedlings in water cultivation. In this experiment, growth disturbances occurred even although micronutrients were applied. The damage was first noticed after four years of fertilization, at which time about 1 kg B per ha had been added. In a parallel treatment where N was applied annually but P and K were only applied every third year, the disturbances were also noted after four years. In this case the trees returned to normal growth after an application of 2.5 kg B per ha in each of years five and seven from the start of the experiment.

Introduction

There are few Swedish reports on growth disturbances in trees caused by deficiencies of micronutrients. It is uncertain whether growth disturbances exist at all in Swedish forests without site manipulations such as commercial applications of fertilization which started about 20 years ago. Still it is almost only stands on mineral soils which are fertilized and only to a minor extent those on peatlands, where the micronutrient status can be expected to be worse. This may also partly explain why so few reports deal with growth disturbances in Swedish forests.

About 25 years ago a number of fertilization experiments were started by our Department in stands of pine and spruce on mineral soils. In the young stands nitrogen was given each year and normally potassium and phosphorus each third year. In the older stands the application intervals were two to three years in the case of nitrogen and about 10 years for phosphorus and potassium. Different combinations of these elements were also applied. Fertilization with micronutrients is included in some of the treatments, selected results of which will be reported here.

Critical levels for growth disturbances caused by boron deficiency

Exposed current needles from the second whorl were sampled each autumn from the above-mentioned experiments and analysed for their contents of macronutrients (N, P, K, Ca and Mg). Each third or fourth year growth measurements of the trees were made and on those occasions different types

of irregular growth, moose grazing, etc., were also recorded. In the early 1970's a relatively high frequency of a previously unobserved type of damage was noticed. Reports from Finland indicated that such damage might be caused by micronutrient deficiencies (Huikari 1974). Consequently, the numbers of trees per plot with this damage were recorded and needle samples were analysed for some of the micronutrient elements (B, Cu, Zn and Mn).

Needle concentrations of Cu, Zn, and Mn showed no clear relation to the growth disturbances. On the other hand, when the boron content of the needles sank below 4—5 μg per g dw, the percentage of damaged trees per plot increased strongly (Fig. 1). The value corresponds well with values in the literature (Stone 1968).

The damage symptoms also coincide well with other reports on growth disturbances caused by boron deficiency (Stone and Will 1965, Raitio and Rantala 1977). In the present experiments the needles sampled came from the routine autumn samplings, which means that trees with serious symptoms were not sampled and that the boron values consequently represent the more normal trees of the plots. For that reason it is highly probable that the boron content within damaged parts of the trees is still lower than the contents indicated in Figure 1.

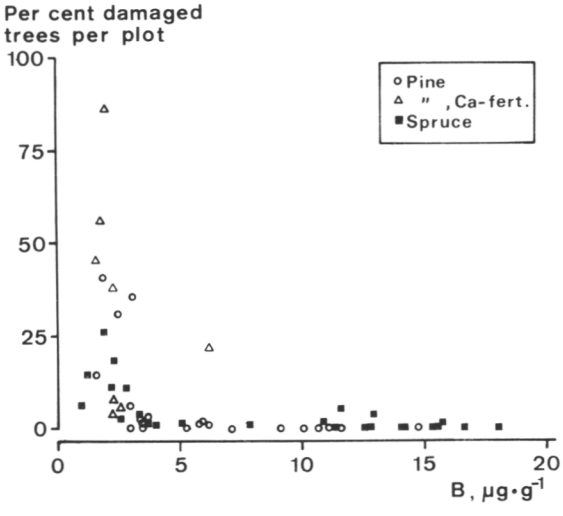


Figure 1. B content in current needles, sampled after the growing period, plotted versus per cent damaged trees per plot.

Effects of N, P, K and Ca fertilization on boron concentration in needles

Fertilization is nearly always done with the aim of increasing biomass production and it is a common event that concentrations of elements not applied will decrease after fertilization. If this decrease depends only on a larger biomass and not on a decreased uptake of the element, it is usually called "dilution effect".

One of the experimental series consists of four blocks in slow-growing pine forest on sandy till situated in four different areas with one block in each area. Two of the areas are in mid-Sweden in an area with nutrient — poor bedrock (Lövnäs and Bleckstugan, altitude 450 m) and the other two in northern Sweden (Häggsjöliden and Själlarimsheden, altitude 280 and 275 m); all four areas are far from the sea. The pine stands were between 85—130 years old at the start in 1959. During the period 1959—1978 the stands were fertilized with N, P, K and $CaCO_3$ alone and in factorial combinations. The total amounts added were 780 kg N, 123 kg P, and 244 kg K per ha. Liming with 4 000 kg Ca was done at the start in 1959 (Burgtorf 1981).

In all four areas the B-concentrations decreased during a 10-year period from the start and thereafter became rather constant. As an example, the results from Lövnäs are shown in Figure 2. In Table 1 the B-values

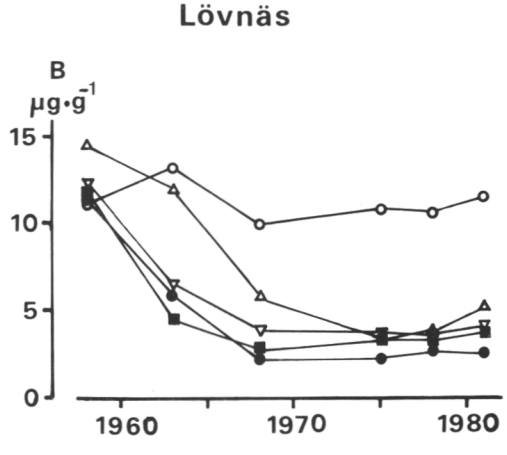


Figure 2. Effect of different fertilization treatments on B-concentration in current needles from a mature pine stand. The samples were taken in the autumns. Fertilization treatments: △ = N, ▽ = NPK, ● = NCa, ■ = NPKCa, ○ = control.

are presented for all areas from 1968 onwards. In the two areas in northern Sweden, control values as low as 7 μg per g dw occur while in mid-Sweden the values are somewhat higher, which is in agreement with results reported by Möller (1982). N-treatment decreased the B content fairly considerably and the NCa- and NPKCa-treatments resulted in still lower values. Whether this is a dilution effect only or whether there is a depressed B-uptake cannot be distinguished from the results in Table 1. However, judging from the current stem growth values it is very likely that the Ca treatment caused a reduced B uptake. In a young spruce stand fertilized for many years (Table 2) the B-values were severely reduced by N-fertilization (Fig. 3: 0, N2 and N3 treatment). Also the P-fertilization (N2, N2P1, N2P2 and N3, N3P1 treatment respectively) reduced the B-values. Most of the lower B-values can be explained as a dilution effect. If we use stem growth as a crude measure of standing biomass (which is not perfectly correct according to Axelsson 1983, but might be good enough here) then N-fertilization does not seem to influence the B-uptake. On the other hand, the B-values indicate a reduced B-uptake after P-fertilization. But in order to get a true answer we need many more values of the B-concentrations in trees and biomass figures from the same stand at the same time.

The micronutrient fertilization with 2.8 kg B per ha for a 12-year period maintained the B-concentrations in the needles at about the same levels as for the control plots.

However, in contrast to the above-mentioned examples a very fast decrease of the B-concentrations occurred after NPK-fertilization in a young pine stand (Fig. 5, F-treatment). Already one growing period after NPK-application the B-values had decreased so much that the cause could not only be a dilution effect but must also have involved a decreased B-uptake.

Table 1. Boron concentration, μg per g dw, in current needles and yearly stem growth in four Scots pine stands after fertilization each second or third year from 1959 onwards. The figures are mean values for three or four occasions in 1968 or later. Compare also figure 2.

Experimental area	Fertilization treatments O	N	NPK	NCa	NPKCa
Lövnäs	10.8	4.4	3.8	2.5	3.4
Bleckstugan	12.0	4.6	3.7	3.9	2.9
Häggsjöliden	7.4	3.5	3.3	2.5	2.6
Själlarimsheden	7.7	2.4	3.0	2.2	2.3
Mean	9.4	3.7	3.4	2.8	2.8
Yearly stem growth, mean 1969—1978, $m^3 \cdot ha^{-1} \cdot year^{-1}$	2.7	5.6	6.6	5.4	5.2

Effects of B-, Cu-, Zn-, and Mn-fertilization on needle concentrations of these elements

In one of the young pine experiments four plots were fertilized with rather high

Table 2. Fertilizer regimes for E26 A Stråsan. Added elements in kg per ha.

Year	N1	N2	N3	P1	P2	K	Mg	Ca	B	Co	Zn	Cu	Mn	Mo
1967	60	120	180	20	40	80	22	4000	0.23	0.01	0.20	0.34	0.77	0.01
1968	"	"	"	—	—	—	—	—	—	—	—	—	—	—
1969	"	"	"	20	40	80	22	—	0.80	0.05	0.72	1.20	2.70	0.05
1970	40	80	120	10	20	—	—	—	—	—	—	—	—	—
1971	"	"	"	—	—	—	—	—	—	—	—	—	—	—
1972	"	"	"	—	—	—	—	—	—	—	—	—	—	—
1973	"	"	"	—	—	—	—	—	—	—	—	—	—	—
1974	"	"	"	20	40	80	22	—	0.58	0.04	0.51	0.86	1.93	0.04
1975	"	"	"	—	—	—	—	—	—	—	—	—	—	—
1976	"	"	"	—	—	—	—	—	—	—	—	—	—	—
1977	30	60	90	20	40	80	22	—	1.17	0.07	1.03	1.72	3.86	0.07
1978	"	"	"	—	—	—	—	—	—	—	—	—	—	—
1979	"	"	"	—	—	—	—	—	—	—	—	—	—	—
1980	"	"	"	20	40	80	22	—	1.17	0.07	1.03	1.72	3.86	0.07
1981	"	"	"	—	—	—	—	—	—	—	—	—	—	—
1982	"	"	"	—	—	—	—	—	—	—	—	—	—	—

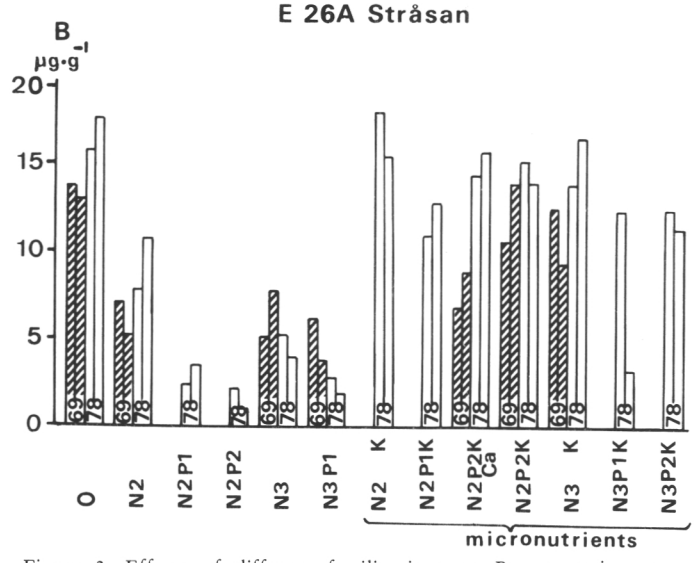


Figure 3. Effects of different fertilizations on B-content in exposed current spruce needles samples in the autumns of 1969 and 1978. Each histogram bar represent one plot.

Table 3. Fertilizer regimes for the four plots in experiment E41 Lisselbo which got micronutrient fertilization in addition to the macronutrients. One plot was fertilized with all elements while for the other three plots one element per plot was excluded, respectively P, Mg and S. Added elements in kg per ha.

Year	N	P	K	Mg	S	Cu	Zn	Mn	B	Mo
1969	120	40	80	50	40	—	—	—	—	—
1970	"	—	—	—	—	12	12	12	5	1
1971	80	—	—	—	—	—	—	—	—	—
1972	"	20	40	—	—	—	—	—	—	—
1973	"	—	—	50	40	12	12	12	5	1
1974	"	—	—	—	—	—	—	—	—	—
1975	60	40	80	—	—	—	—	—	—	—
1976	"	—	—	—	—	—	—	—	—	—
1977	40	40	80	50	40	12	12	12	—	1
1978	"	—	—	—	—	—	—	—	—	—
1979	"	—	—	—	—	—	—	—	—	—
1980	"	40	80	50	40	—	—	—	—	—

dosages of the micronutrients Cu, Zn, Mn, B and Mo (Table 3).

Needle analyses for Mo were not made but of the other four elements only B was easily taken up by the trees (Fig. 4). Cu and Mn did not influence the needle concentrations at all and for Zn the values increased only slowly and to a small extent. Following the B-dosages of 5 kg B per ha in 1970 and 1973 the B-concentration rose each year to 80—100 µg B per g dw. Although these high

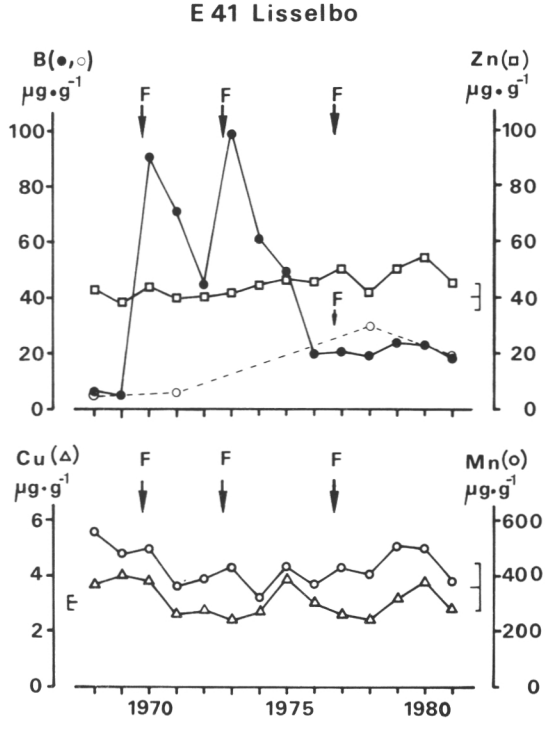


Figure 4. Effects of fertilization with B, Zn, Cu, and Mn on current needle content of respective element. F indicates the time when the fertilization was done. In 1977 no B was given to the plots represented by the unbroken line. The plot with the broken B-line was given 2.5 kg B · ha^{-1} in 1977. Compare also table 3. Mean values and standard deviations for respective elements from a control plot sampled on four occasions during the period are given near the Y-axis.

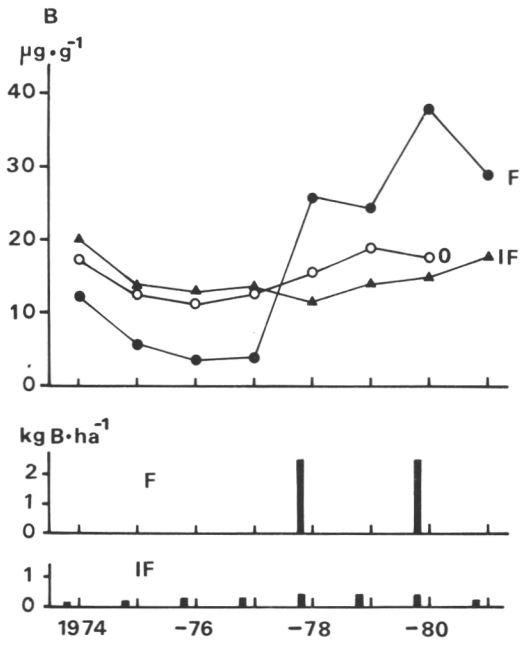


Figure 5. B-concentration in current pine needles sampled in the autumns (above) after B-fertilization (below) in a young Scots pine stand. F means fertilized once a year. IF denotes irrigation and fertilization five day a week during the growing period, 0 are controls.

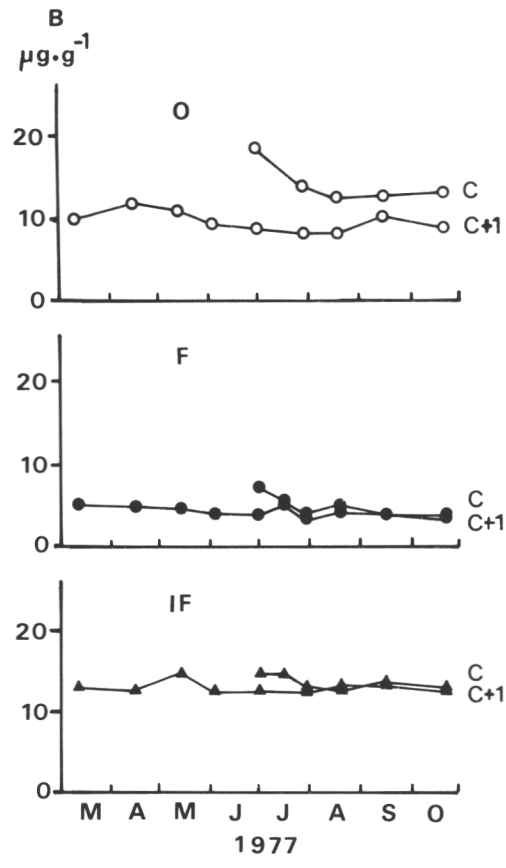


Figure 6. B-concentrations in needles during the growing period in 1977 from the same stand as in figure 5. C = current needles, C+1 one-year-old needles.

B-contents might be at toxic levels (Stone 1968), no damage was observed when the routine growth measurements were made in the autumns of 1971 and 1974. This does not mean that no trees were damaged but only that the damage cannot have been serious.

According to many reports, B is probably taken up passively by the plants as undissociated boric acid and is transported within the transpiration stream (Gupta 1979), which may explain the very rapid B-increase in the needles. The very rapid decrease after the high values may partly depend on the relative immobility of B within the trees (Stone 1968) and the current needle concentrations reflect the available B in soil more than the B-pool of the tree (compare also Fig. 7). After only four years the level had stabilized around 20 μg per g dw and this might be the level that corresponds to the B-mineralization rate for the stand. This is supported by the broken B-line in Figure 4 which illustrates a plot fertilized once with 2.5 kg B per ha and no other fertilizers. After two summers the B-value for trees in this plot was also about 20 μg per g dw.

Figures 5 to 7 are from a 15—20 year old pine stand in an experiment conducted by the Swedish Coniferous Forest Project. The treatments started in July 1974 and, apart from the control (0) were; fertilization once a year with N and each third year with P and K and in 1978 and 1980 also B (Treatment F); irrigation and fertilization five days a week during the growing period with a very diluted nutrient solution containing all essential nutrients (Treatment IF). From the start in July 1974 to autumn 1981 sum of the applied fertilizers for treatment F was: 610 kg N, 90 kg P, 180 kg K, and 5 kg B per ha, and for the treatment IF: 1170 kg N per ha and all other nutrients in proportions to N according to Ingestad (1967), i.e., 150 kg P, 760 kg K and 2.34 kg B per ha.

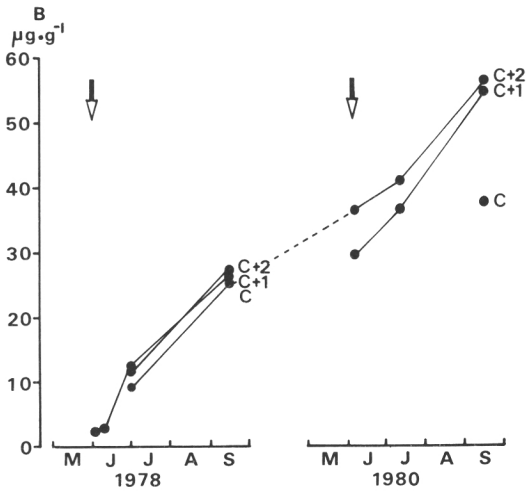


Figure 7. B-concentrations in different year-classes of pine needles after fertilization with 2.5 kg B per ha in the early summers of 1978 and 1980 as indicated by arrows. C = current needles, C+1 and C+2 respective one- and two-year-old needles.

In 1977 growth disturbances occurred in both the F and IF treatments and it was decided to fertilize the F plots with 2.5 kg B per ha (Fig. 5). But as the nutrient solution applied on IF plots also contained B, no extra B-fertilizer was added to these plots although the B dosage obviously was too low. Growth disturbances in the F-plots decreased during 1978 and 1979 but did not disappear. At that time there were difficulties in getting B-analyses made and without actual B-values and remaining irregular growth of the trees the F plots were refertilized with 2.5 kg per ha in the spring 1980. Later, when the analyses could be done, it appeared that the F-treated plots had B values within the critical range for growth disturbances before the first time B was applied (Fig. 5). The needle contents from the IF treatments were well above what normally is the critical range (Figs 5 and 6). But why, then, were the trees damaged? There is no simple answer to the question but perhaps it is partly a sampling artefact. According to Stone (1968), the following may be part of the explanation: Boron very probably moves with the transpiration stream within the tree and when boron reaches the needles it is not, or only to a very small extent, mobile. Boron is important for the function of the meristems but the supply to the meristems depends on the uptake by the roots. The demand for boron must be largest during the shoot elongation period, the period during which the damage develops. Damage can thus occur even if the B-contents of adjacent needles are satisfactory. The B-concentrations shown in Figures 5 and 6 are from routine samplings, which implies healthy-looking needles from the third whorl. New results from transpiration measurements in the same stand have shown that transpiration rate in pine is often fastest from the second to fourth whorl and decreases somewhat above these whorls. This transpiration pattern is most frequent during the shoot elongation and needle developing period (E. Mattsson-Djos, pers. comm.) and may give lower B-contents above the sampled third whorl. The B-content of damaged shoots may thus have been much lower than indicated by Figures 5 and 6. Here it can also be mentioned that the ratio B to N for the nutrient solution was $20 \cdot 10^{-4}$, while for the current needles from the IF treatments shown in Figure 6 it was $6 \cdot 10^{-4}$. This suggests that part of the boron has been lost on the way between irrigation equipment and the trees.

The application of 2.5 kg B per ha in early summer 1978 resulted in a fast increase in all needles regardless of their age (Fig. 7). A new application in 1980 further raised the values but the current needles in the autumn had a much lower value than the older ones. The results are in agreement with the earlier-mentioned reports that boron moves with the transpiration stream and is not easily translocated between different year-classes of needles.

References

AXELSSON, B. (in press). Fördelning av trädets nettoproduktion på stam, grenar, blad och rötter. Paper presented at the Faculty of Forestry Conference, Dec. 1982. Skogsfakta (Suppl.), Swedish University of Agricultural Sciences, Garpenberg. (Swedish)

BURGTORF, H. 1981. Effekten av växtnäringstillförsel till några tallbestånd på näringsfattig mark i kyliga klimatlägen. (The effect of supply of plant nutrients to some pine stands on poor and cold sites). — Reports in Forest Ecology and Forest Soils 37: 1—34, Swedish University of Agricultural Sciences, Uppsala.

GUPTA, U.M. 1979. Boron nutrition of crops. Advances in Agronomy 31: 273—307.

HUIKARI, O. 1974. Hivenravinteet ja puiden kasvu. — Metsä ja Puu 11: 24—25.
INGESTAD, T. 1967. Methods for uniform optimum fertilization of forest tree plants. 14th IUFRO-Congress, Munich. Section 22: 265—269.
MÖLLER, G. 1982. Borbristskador efter upprepad kvävegödsling på fastmark. (Growth disturbances from boron deficiency on mineral soil after refertilization with nitrogen.) The Institute for Forest Improvement, Uppsala. Yearbook 1982: 47—70.
RAITIO, H. & RANTALA, E-M. 1977. Männyn kasvuhäiriön makro- ja mikroskooppisia oireita. Summary: Macroscopic and microscopic symptoms of a growth disturbance in Scots pine. Commun. Inst. For. Fenn. 91(1): 1—32.
STONE, E.L. 1968. Microelement nutrition of forest tree: A review. — In: Forest fertilization, theory and practice. Symp. For. Fert., April, 1967. Knoxville, USA. Tennessee Valley Authority, Muscle Shoals, Alabama, p. 132—175.
— & WILL, G.M. 1965. Boron deficiency in Pinus radiata and P. pinaster. — Forest Science 11(4): 425—433.

Total of 9 references

NUTRIENT IMBALANCIES IN CONIFEROUS STANDS IN SOUTHERN GERMANY

Karl-Eugen Rehfuess, Christof Bosch and E. Pfannkuch

Two examples of imbalanced nutrition in coniferous stands of southern Germany are described as follows:

a) Induced P and Mg deficiency showed up in a fertilization experiment (O — N — NPKMg) in a pole stand of Scots pine (*Pinus sylvestris* L.) growing on a podzolic soil with pseudogley features derived from layered cretacious substratum. In this case repeated fertilization with only nitrogen resulted in a lowering of foliar P and Mg levels down to threshold values mainly by a dilution effect. This reduction could be avoided by additional PKMg dressings, and the latter treatment yielded the best growth responses.

b) Extreme magnesium deficiency in unfertilized stands of Norway spruce (*Picea abies* Karst.) occurs in the Bavarian Forest at higher altitudes (> 1000 m). It is associated with very low calcium contents in the needles, but with excellent nitrogen and phosphorus nutrition. The stands, growing on acid or podzolic brown forest soils derived from granite and gneiss, exhibit typical deficiency symptoms, premature needle shedding and growth depressions. There is evidence that acid deposition may contribute to this growth disturbance, which seems to be a rather recent phenomenon. Acid rain adds nitrogen to the systems, but may leach calcium and magnesium from needles and soils. Mg deficiency seems to be associated with a decrease in frost hardiness of spruce needles.

Phosphorus and magnesium deficiency in older pine stands

Scots pine (*Pinus sylvestris*) stands in southern Germany often grow on sites, which are poor in N, P, Ca, and Mg and/or are degraded by the interferences of man like burning, grazing or litter raking. Those soils are generally very acid and characterized by unfavorable biologically inactive raw humus. It is well known, that pines on these substrata suffer from N deficiency. Therefore fertilization with N (100—150 kg · ha^{-1} repeated every 5—7 years) is a common amelioration practice in older stands. On the other hand it was assumed hitherto, that the amounts of available P, K, Ca and Mg in the soils although being low — would be sufficient for good pine growth on most mineral soils even after repeated N fertiliz-

ation (Wehrmann 1956, Zöttl and Kennel 1962, Kennel and Wehrmann 1967, Kennel 1967, Kreutzer 1967, Franz and Bierstedt 1975).

In Bavaria there exists only one trial, which, by comparing the effects of fertilization with N alone and with combined NPKMg, gives the possibility to check, whether this earlier conclusion of adequate supply of pines with all other nutrients except N still holds true under all conditions.

Experimental design

The experiment BUL 240 Eichenhänge (FA. Burglengenfeld) was established in 1961 by J. Wehrmann and F. Franz in a pole stand of pines 54 years old (site class IV. 2 according to yield table of Wiedemann 1943, moderate thinning). It grows on a podzolic brown forest soil (spodic dystrochrept), showing pseudogley features in deeper horizons, which is derived from sandy and clayey cretaceous sediments. The trial involves three treatments (O; N; NPKMg) replicated twice.

Table 1 describes the experimental design in detail; for the evaluation techniques see Preuhsler and Rehfuess 1982.

Table 1. Description of fertilizer treatments in experiment BUL 240 Eichenhänge (nutrient amounts in kg/ha).

	Treatment	
Date	N	NPKMg
5.61	100 N 66 Ca	100 N 79 P 116 K 30 Mg 290 Ca
6.62	100 N 66 Ca	100 N 79 P 116 K 30 Mg 290 Ca
5.63	100 N 66 Ca	100 N 79 P 232 K 60 Mg 290 Ca
5.72	120 N 66 Ca	120 N 79 P 208 K 48 Mg 290 Ca
Total	420 N 264 Ca	420 N 316 P 672 K 168 Mg 1160 Ca

N as kalkammonsalpeter (4 × 5 dt/ha): P as superphosphate (4 × 10 dt/ha); KMg as patentkali (30 dt/ha); Ca in kalkammonsalpeter and superphosphate

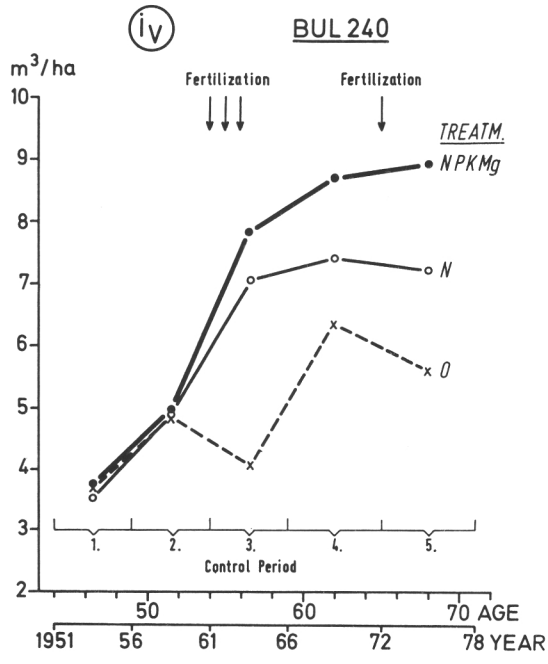


Figure 1. Volume increment (total stemwood including bark) of experimental units.

Growth reactions

Figure 1 exhibits the growth reactions during five measuring periods, each of which lasted 5 or 6 years. The angle points of each curve indicate the average annual volume increment (total stem wood including bark) within one particular period.

During the ten years prior to the start of the experiment pine growth was rather poor and very similar on all plots irrespective of the experimental unit. The application of NPKMg at 4 different dates (last application 1972!) immediately improved volume growth, and a raised growth level was maintained until today, although it seemed to diminish slightly during the last control

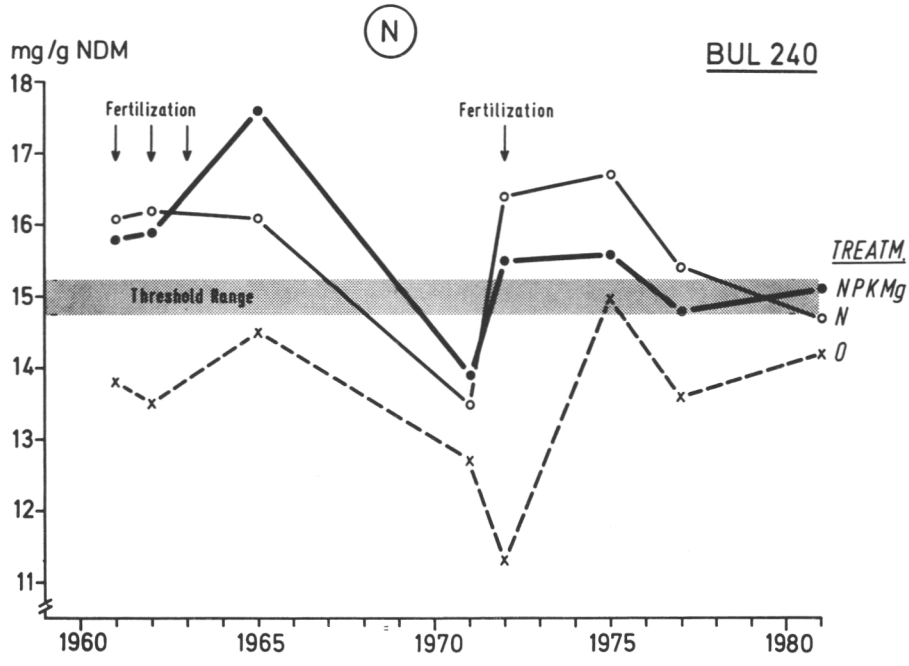


Figure 2. Nitrogen contents of half year old pine needles.

period. Even in this final phase the volume growth in NPKMg treatment amounted to about 9 $m^3 \cdot ha^{-1} \cdot a^{-1}$, which is an additional increment of 3,4 $m^3 \cdot ha^{-1} \cdot a^{-1}$, or 60 % as compared with control stands (5,6 $m^3 \cdot ha^{-1} \cdot a^{-1}$).

Application of N alone at the very beginning of the trial enhanced volume growth to about the same extent as complete fertilization (NPKMg). In the longer run, however, this treatment more and more revealed itself to be inferior, and during the last monitoring period the additional growth caused by N application alone only reached 1,6 $m^3 \cdot ha^{-1} \cdot a^{-1}$ or 29 % of the growth level of control pines.

Foliar nutrient levels

During the first phase of experimentation from 1961—63, both fertilizer treatments considerably improved the N nutrition of the pines, and this effect lasted at least until 1965 (Fig. 2). Between 1964 and 1971 no fertilizer was spread, since the response to the initial application should be monitored. Therefore the N contents of pine needles on all ameliorated plots decreased. Although trees, which had earlier received N, still were superior, they once more started to suffer from N deficiency. The repeated fertilization in May 1972 immediately raised the N contents of pine needles to a sufficient level of supply (15—16 mg N/g), treatment "N" producing the highest levels. The rapid enhancement of volume growth during the first few years of experimentation, occurring in similar ways in both the N and the NPKMg treatment, therefore is supposed to have been caused mainly by improved N supply.

Application of N alone, however, was associated with rather low P contents of pine needles (1,2—1,3 mg/g). Foliar P levels in this treatment were lower as compared with those of control stands and varied within the range of P deficiency. The N/P ratios increased to unusually high values between 11 and 14 (Fig. 3). This decrease of P supply by treatment "N" presumably was due to a dilution effect. Similarly the Ca and Mg contents of pine needles declined after application of N alone during the years from

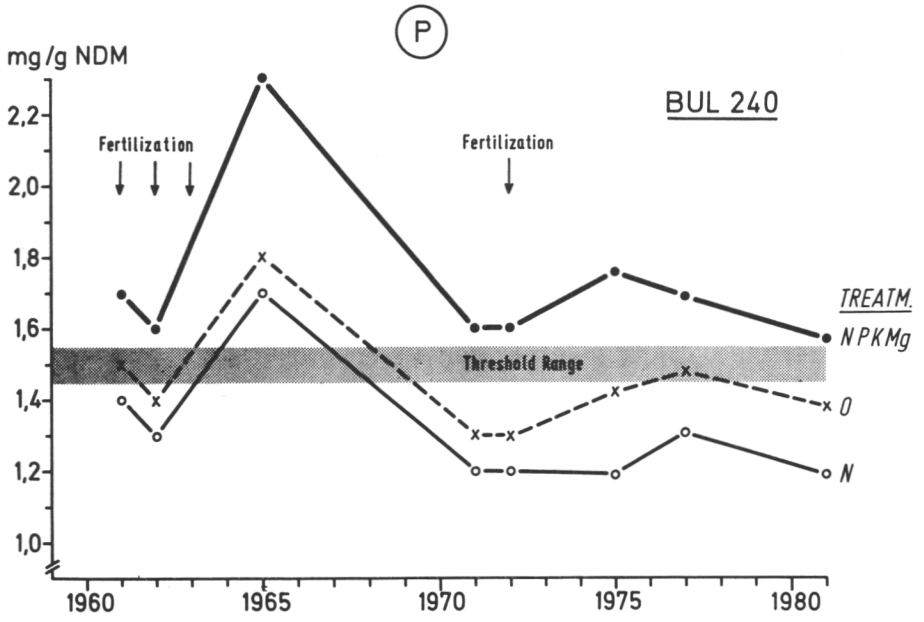


Figure 3. Phosphorus contents of half year old pine needles.

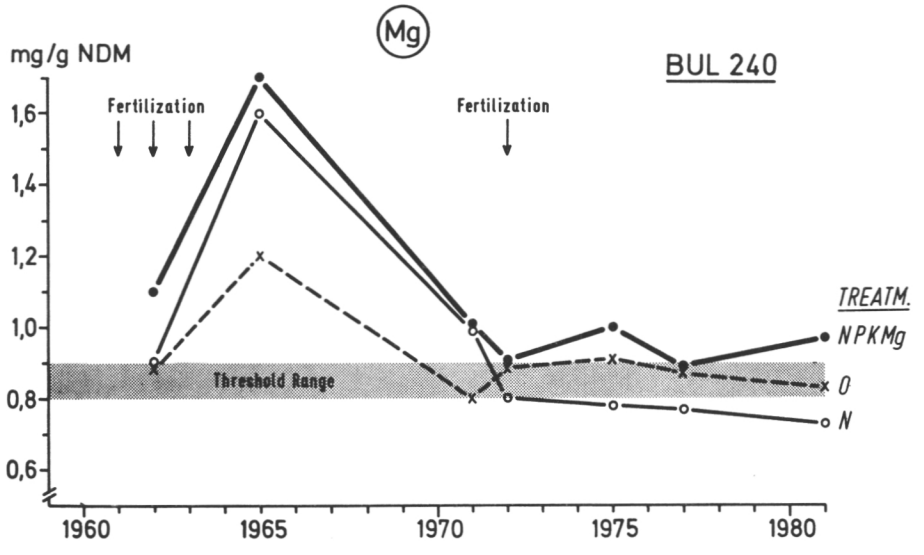


Figure 4. Magnesium contents of half year old pine needles.

1972 onward, and the threshold range for Mg deficiency was also undercut (Fig. 4).

The NPKMg fertilization on the contrary maintained an adequate supply of P (1,6—1,7 mg/g) and Mg (0,9—1,1 mg/g) during the total period of experimentation, and the N/P ratios remained low (9—10).

Consequences

Therefore it is recommended to change from pure N addition to well-balanced NPMg (KCa) fertilization on more sites than was anticipated before (cf. Tamm et al. 1974, Kern and Moll 1976). This trend is expected to be even more pronounced by

the long term effects of acid precipitation, which imports considerable amounts of nitrogen into forest ecosystems but may enhance their Mg, Ca and K losses (Abrahamsen 1980).

Growth disturbances of Norway spruce (Picea abies Karst.) in eastern Bavaria

Description of decline phenomena

Since about 1980, Norway spruce stands of all age classes (5—250 years) at higher elevations (>1000 m, mean annual precipitation >1250 mm) of the Bavarian Forest (Bayerischer Wald) and in the Upper Palatian Forest (Oberpfälzer Wald) along the border to the CSSR show reduced vitality and decline phenomena, the intensity of which has increased in the meantime. The symptoms are as follows:

Chlorosis and succeeding necrosis of older needles starting at needle tips, normally more pronounced on the upper (lighted) side of the needle; premature shedding of older needles; decreasing crown density starting at the inner and lower crown portions; depressed shoot growth and year ring width; rather rapid death of single trees or small tree groups, whereas adjacent trees seem to remain unaffected; decreasing stand density.

In the Bavarian Forest, where a belt of natural spruce forests occurs between 1150 m and the summits of the mountains (top elevation 1458 m), both autochthonous old growth stands and spruce plantations of unknown provenance are affected, the latter however seem to suffer more. Predominant, codominant and suppressed trees may show the same symptoms. The decline phenomena are widespread on acid to podzolic brown forest soils (dystrochrepts) and shallow podzols (ferrods) derived either from granite or gneiss slope sediments. These periglacial deposits are characteristically stratified and divided into a superficial layer (30—80 cm) loose and rich in stones or blocks and a deeper stratum which is dense, compact and exhibits a platy structure as well as an orientation of stony fragments. Root development is generally restricted to the upper layer and hence may be rather shallow.

Results of foliar analyses

In November 1981 we compared, by means of foliar analysis, affected spruces with apparently healthy neighbours in three representative stands (1 older stand and 2 young plantations) on acid to slightly podzolic brown forest soils (2 derived from paragneiss 1 from granite). In each stand 3—5 pairs of trees were selected. Each pair involved 2 adjacent trees of similar age, height, diameter and stand position, obviously growing at the same microsite conditions. One of those trees showed severe symptoms, whereas the second was apparently free from decline phenomena. Needles of all age classes were sampled and analyzed from the uppermost as well as from the 5th or 7th whorl.

In all stands investigated the nitrogen and phosphorus nutrition of both diseased and healthy trees was excellent (Tables 2 and 4). The potassium supply was generally adequate, although healthy trees tended to have slightly more K in their needles. There was evidence, that the Fe, Mn, Cu and Zn levels of unaffected trees normally exceeded those of neighbouring diseased spruces. This observation holds especially true for Mn in sample stand "Dreisessel" and for Zn in all stands (Tables 3 and 5). Nevertheless declining trees presumably didn't suffer from trace element deficiency, since foliar contents normally varied above the threshold

Table 2. Macronutrient contents in the needles of healthy and diseased old Norway spruce trees. Study area Luchsplatzl/FA. Bodenmais Podzolic brown forest soil derived from paragneiss.

Element	Diseased trees Min.	Max.	$\bar{x}$	Healthy trees Min.	Max.	$\bar{x}$
			Year's growth 1981			
N mg/g	16,2	17,7	17,0	14,3	16,9	15,9
P	1,6	1,8	1,7	1,6	2,1	1,9
K	3,6	5,3	*4,4*	5,4	6,1	*5,7*
Ca	0,8	1,6	*1,2*	1,4	2,0	*1,7*
Mg	0,39	0,68	*0,51*	0,58	0,81	*0,69*
			Year's growth 1978			
N mg/g	13,0	14,2	13,7	12,0	14,2	13,2
P	1,0	1,1	1,0	1,2	1,3	1,2
K	3,5	4,6	*4,1*	4,0	5,9	*4,8*
Ca	1,8	3,9	*2,5*	2,7	5,6	*4,0*
Mg	0,17	0,29	*0,24*	0,27	0,84	*0,52*

Data of three tree pairs, each involving one unaffected and one diseased tree with comparable dimensions and sociological position. Needles originated from the 7th whorl. Sampling date 24.11.1981.

Table 3. Micronutrient contents in the needles of healthy and diseased old Norway spruce trees. Study area Luchsplatzl/FA. Bodenmais podzolic brown forest soil derived from paragneiss.

Element	Diseased trees Min.	Max.	$\bar{x}$	Healthy trees Min.	Max.	$\bar{x}$
			Year's growth 1981			
Fe µg/g	35	40	37	40	52	45
Mn	112	187	158	173	193	181
Cu	3	7	5	3	5	4
Zn	7	18	13	16	24	20
			Year's growth 1978			
Fe µg/g	59	68	64	64	92	74
Mn	168	209	194	178	306	221
Cu	3	4	3	2	5	4
Zn	8	12	10	12	20	15

For comments see Table 2.

Table 4. Macronutrient contents in the needles of healthy and diseased young Norway spruce trees. Study area Dreisessel/FA. Neureichenau podzolic brown forest soil derived from granite.

Element	Diseased trees Min.	Max.	$\bar{x}$	Healthy trees Min.	Max.	$\bar{x}$
			Year's growth 1981			
N mg/g	16,7	25,2	20,0	15,6	19,7	17,9
P	1,9	3,1	2,2	1,7	2,2	2,0
K	4,9	6,8	5,8	6,0	7,2	6,3
Ca	1,11	2,15	1,71	2,15	3,14	2,77
Mg	0,17	0,29	0,21	0,30	0,47	0,40
			Year's growth 1978			
N mg/g	12,6	15,9	14,0	12,4	14,6	13,2
P	1,5	2,5	1,8	1,3	1,4	1,3
K	4,6	6,2	5,3	4,0	4,8	4,4
Ca	3,6	4,7	4,0	5,3	6,8	5,9
Mg	0,13	0,23	0,16	0,26	0,35	0,29

Data of four tree pairs, each involving one unaffected and one diseased tree with comparable dimensions and sociological position. Needles originated from the 5th whorl. Sampling date 23.11.1981.

ranges. Al contents of spruce needles were not significantly different between healthy and diseased specimens.

The most striking difference, on the contrary, occurred with magnesium and calcium. In all sample stands investigated, the level of supply of these elements was in general very low. In each particular pair of sample spruces, the healthy tree showed higher Mg and Ca contents in the leaves than its diseased neighbour.

The affected trees all suffered from extreme Mg deficiency (cf. Zech and Popp 1983), and this shortage was normally more pronounced in older than in younger needles

Table 5. Micronutrient contents in the needles of healthy and diseased young Norway spruce trees. Study area Dreisessel/FA. Neureichenau podzolic brown forest soil derived from granite.

Element	Diseased trees Min.	Max.	$\bar{x}$	Healthy trees Min.	Max.	$\bar{x}$
			Year's growth 1981			
Fe µg/g	45	68	52	36	62	52
Mn	158	355	*289*	523	848	*665*
Cu	3	4	4	4	7	5
Zn	16	24	20	21	47	37
Al	54	129	102	72	112	89
			Year's growth 1978			
Fe µg/g	74	124	92	62	101	78
Mn	438	632	*561*	674	1281	*1044*
Cu	4	5	4	3	4	4
Zn	21	46	29	26	48	32
Al	183	288	246	108	331	182

For comments see Table 4.

and on soils derived from granite — inherently low in Mg — as compared with paragneiss substrata containing at least moderate amounts of this element (Table 6).

It is difficult to evaluate the Ca data, since the threshold values for this element and for older Norway spruce stands are not yet well established. Nevertheless it is quite sure, that the Ca levels observed are very low in comparison with the results of all inventories on the nutritional status of Norway spruce carried out in southern Germany (Strebel 1960, Rehfuess and Moll 1965, Rehfuess 1969 and 1973, Elling et al. 1976) and quite near to the deficiency levels as reported by Morrison (1974) and Van den Burg (1979). Electron probe microanalysis (EPMA) combined with scanning electron microscopy (SEM) of representative individual needles (site Luchsplatzl; lower parts of the crown; N aspect; needle age class 4; sampling in March 82) detected a marked accumulation of calcium in the immediate surroundings of the stomata of healthy spruces, whereas this peak was less pronounced with diseased trees. This shortage of Ca may hinder the normal functions of stomata. The potassium distribution was not affected. Unfortunately the sensitivity of the x-ray technique used was not strong enough to also localize Mg on and within the leaves.

Needles from healthy spruce trees (site Luchsplatzl; whorl 7; needle age class 1—5; sampling date Nov. 81), irrespective of age,

Table 6. Reaction and K, Ca and Mg contents of representative soil forms in the study area.

Site and soil form	Horizon	Depth cm	pH H_2O	pH $CaCl_2$	K_T	Ca_T mg/g	Mg_T
Luchsplatzl (C_3)							
Podzolic brown	OF	9— 2	4,38	3,45	1,6	0,58	0,27
forest soil der.	OH	2— 0	4,15	3,40	1,8	0,91	0,37
from paragneiss	A_{eh}	0—10	4,37	3,70	13,1	5,53	3,35
	A_hB_v	10—21	4,35	3,95	15,4	5,56	4,12
	B_v	21—41	4,42	4,15	16,0	6,78	3,98
	II B_v	41—68	4,57	4,35	17,2	7,18	5,47
	C_vB_v	68—94	4,67	4,60	19,2	8,50	6,96
Dreisessel (A_1)							
Podzolic brown	OF	7— 3	4,45	3,70	3,0	1,88	0,54
forest soil der.	OH	3— 0	4,13	3,25	15,1	1,52	0,63
from granite	A_{eh}	0—28	4,46	4,05	28,0	0,79	0,76
	(Go)A_hB_v	28—49	4,60	4,25	30,0	1,04	1,00
	B_v	49—	4,76	4,45	35,0	2,01	1,33

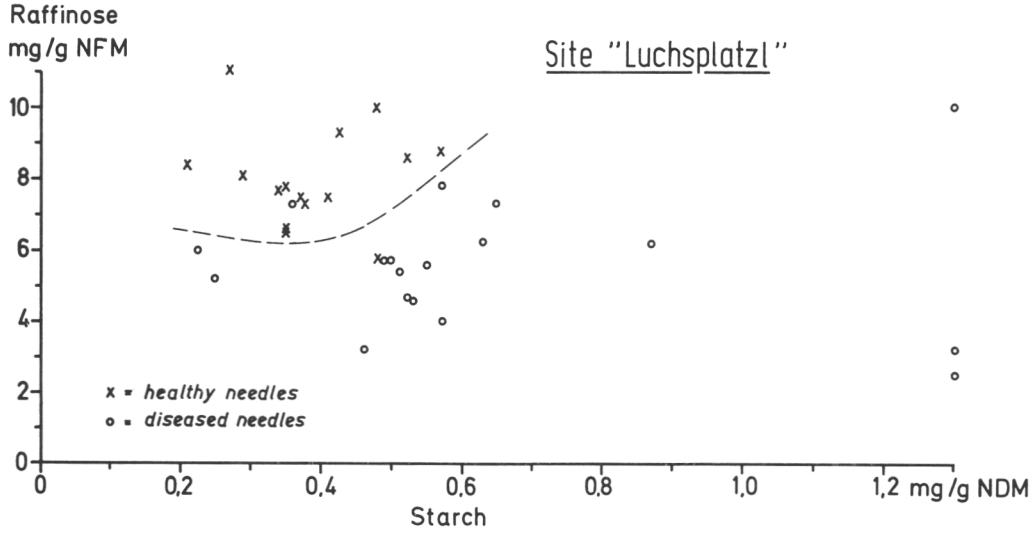


Figure 5. Scatter diagram for raffinose vs. starch contents in spruce needle fresh matter.

generally contained less starch, but more raffinose as compared with diseased neighbours. This significant shift of the starch/raffinose ratio (Fig. 5) may indicate a decrease in frost hardiness of the foliage of affected spruces (Kandler et al. 1979, Vogl et al. 1972, Ranft et al. 1979).

Conclusions

From these preliminary observations we have derived a working hypothesis to explain the recent Norway spruce decline at higher elevations in forest regions of eastern Bavaria. It may hold true only, if root pathogens or abiotic agents damaging the roots primarily are not involved — in fact until now those were not yet detected:

Affected trees suffer from severe Mg deficiency; they are also poorly supplied with Ca. The deficiency symptoms are most pronounced under conditions of intensive illumination, where the deterioration of chlorophyll is increased by photooxidation. On the other hand the N and P nutrition of both healthy and diseased trees is excellent. This finding may indicate, that affected spruces don't exhibit any general and drastic reduction of the absorbing capacity of their root systems in relation to the foliage mass and at the very beginning of the disease.

Since this shortage of magnesium and calcium in spruce occurs on substrata differing considerably in the contents of both elements, we don't feel that a depletion of the soils is the most prominent factor causing the deficiency. We rather suppose this recent deficiency to be mainly a consequence of enhanced dissolution of Mg and Ca from the needles either by SO_2/SO_3— dissolving in the water films on the needles and in the free space and forming H_2SO_3/H_2SO_4— or by strong acids already diluted in the precipitation (cf. Horntvedt 1979, Horntvedt et al. 1980, Jacobson 1980, Tukey 1970). This assumption is supported by our accidental observation, that under special weather conditions gypsum cristals appear in and around the antestomatal cavities, and that they are significantly more numerous on the relatively Ca rich foliage of healthy than on that of affected trees. The Mg and Ca deficiency is accelerated by the fact, that wet and dry deposition in a forest opening imports rather high amounts of N and S in the area under investigation (~ 20 kg N; 19 kg SO_4—S and 0,5 kg $H^+ \cdot ha^{-1} \cdot a^{-1}$ in 1980/81; pH 4,47) but only few Mg and Ca (~1 and ~5 $kg \cdot ha^{-1} \cdot a^{-1}$, respectively; Dunkl 1982). Due to the fact that the soils a rather rich in potassium, this element seems to be replaced very rapidly by root uptake (cf. Tukey 1970, Horntvedt 1979). The absorption of calcium and magnesium, however, may be not efficient enough to counteract the leaching from the foliage.

The insufficient supply of Norway spruce with magnesium and calcium should be most severe on soils derived from granite, poor in earth alkaline elements, on strongly podzolized substrata and on those allowing only shallow rooting in a stony slope deposit. It will be aggravated by leaching of both elements from the top horizons as increased by acid deposition (Abrahamsen 1980, Rehfuess 1981).

The magnesium deficiency of needles may reduce their physiological activities in general and especially their frost hardiness. Therefore sudden and extreme temperature falls after warm period in early spring and/or during mid-winter may presumably cause or intensify chlorosis and premature death of needles and trees. The older needles should be affected more than younger ones, since they contain less Mg and K and are photosynthetically less effective. It should be stated that the symptoms of Norway spruce decline are very similar to those of a late frost damage in April 1981 in Sitka spruce plantations in western Scotland as reported by Redfern (1982, pers. communication). The suggested interaction of acid deposition, nutritional status, frost hardiness and frost events would explain the extreme tree-to-tree variation with regard to the intensity of the disease observed in our sample stands as well as the rather sudden outbreak of the disease. Leaves which are injured by adverse climate or by nutritional or physiological disorders are *vice versa* more susceptible to leaching than those from healthy and vigorous plants (Tukey 1970).

It should be mentioned, that spontaneous temperature falls occurred in April 1980 and 1981 as well as in the night from December 31, 1978 to January 1, 1979. Klimo (1979) observed, that the needle fall in a spruce stand in Moravia rised during April June after this latter event to 1500 kg/ha as compared with 550—730 kg/ha in the years before.

A depression of gas exchange and photosynthesis due to Mg and Ca deficiency and a reduction of needle mass may decrease the supply of roots with carbohydrates, thus gradually slowing down root activity and nutrient or water absorption. A general decline of tree vitality may be the result as well as an increased susceptibility to root pathogens, to needle cast fungi and to insects feeding on the foliage.

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References

ABRAHAMSEN, G. 1980. Acid precipitation, plant nutrients and forest growth. Proc. Intern. Conference on Ecological Impact of Acid Precipitation, Sandefjord, Norway, p. 58—63.

VAN DEN BURG, J. 1979. Calcium status of Corsican pine (Pinus nigra ssp. laricio) and top-dying. Rapport Nr. 212 Rijksinstituut "De Dorschkamp" Wageningen.

DUNKL, J. 1982. Der Stoffeintrag mit dem Freiland- und Bestandesniederschlag an drei Stationen in verschiedenen Waldgebieten Bayerns. Dipl.Arbeit Univ. München.

ELLING, W. et. al. 1976. Nationalpark Bayerischer Wald. Klima und Böden, Waldstandorte. Bayer. Staatsmin. f. Ern., Landw. u. Forsten.

FRANZ, F. & BIERSTEDT, W. 1975. Wirkung großflächiger Flugzeugdüngung mit Kalkammonsalpeter auf den Volumenzuwachs von Kiefernbeständen im Bayerischen Forstamt Bodenwöhr/ Oberpfalz Forstwiss. Cbl. 94: 310—314.

HORNTVEDT, R. 1979. Leaching of chemical substances from tree crowns by artificial rain. Mitt. IUFRO Tagung s. 2.09 "Luftverunreinigung" Ljubljana 1978, p. 115—125.

— , DOLLARD, G. J. & JORANGER, E. 1980. Effects of acid precipitation on soil and forest. 2. Atmosphere — vegetation interactions. In: Drablos, D. & Tollan, A. (eds.), Ecological Impact of acid precipitation, p. 192—193.

JACOBSON, J.S.M. 1980. The influence of rainfall composition on the yield and quality of agricultural crops In: Drablos, D. & Tollan, A. (eds.), Ecological Impact of acid precipitation, p. 41—46.

KANDLER, O., DOVER, C. & ZIEGLER, P. 1979. Kälteresistenz der Fichte. I. Steuerung von Kälteresistenz, Kohlenhydrat- und Proteinstoffwechsel durch Photoperiode und Temperatur. Ber. Dtsch. Bot. Ges. 92: 225—241.

KENNEL, R. 1967. Ertragskundliche Ergebnisse neuer Düngungsversuche in Kiefern-, Fichten- und Buchenbeständen Bayerns. Forstwiss. Cbl. 86: 13—28.

— & WEHRMANN, J. 1967. Ergebnisse eines Düngungsversuchs mit extrem hohen Stickstoffgaben in einem Kiefernbestand geringer Bonität. XIV IUFRO-Kongress München Bd. VI: 216—231.

KERN, K.G. & MOLL, W. 1976. Melioration von streugenützten Standorten unter Anwendung von Stickstoff-Depot-Dünger Allg. Forst- u. Jagztg. 147: 192—200.

KLIMO, E. 1979. Nutrient cycling within the ecosystem of a man-made spruce forest. In: Klimo, K. (ed.) Proc. Symp. "Stability of spruce forest ecosystems", Brno 1979.

KREUTZER, K. 1967. Ernähungszustand und Volumenzuwachs von Kiefernbeständen neuer Düngungsversuche in Bayern. Forstwiss. Cbl. 86: 28—53.

MORRISON. J.K. 1974. Mineral nutrition of conifers with special reference to nutrient status interpretation. A review of literature. Dept. Environment, Can. Forestry Service Publ. No. 1343, Ottawa.

PREUHSLER, T., & REHFUESS, K.E. 1982. Über die Melioration degradierter Kiefernstandorte (Pinus sylv. L.) in der Oberpfalz. Forstwiss. Cbl. 101 (in press).

RANFT, H. et al. 1979. Untersuchungen zum Zusammenwirken von Immissions- und Frosteinfluß im Fichten-Rauchschadgebiet. Beitr. f. d. Forstwirtsch. 4: 160—165.

REHFUESS, K.E. & MOLL, W. 1965. Orientierende Untersuchungen über den Ernährungszustand von Fichtenbeständen auf Jungmoräne in Oberschwaben. Allg. Forst- u. Jagdztg. 136: 211—223.

— 1969. Ernährungszustand und Kernfäulebefall älterer Fichtenbstände auf der Schwäbischen Alb Mitt. Verein Forstl. Standortskunde u. Forstpflanzenzüchtung 19. 6.

— 1973. Kernfäulebefall und Ernährungszustand älterer Fichtenbestände (Picea abies Karst.) im Wuchsgebiet "Baar-Wutach". Mitt. Verein Forstl. Standortskunde u. Forstpflanzenzüchtung 22.

— 1981. Über die Wirkungen der sauren Niederschläge in Waldökosystemen. Forstwiss. bl. 100: 353—400.

STREBEL, O. 1960. Mineralstoffernährung und Wuchsleistung von Fichtenbeständen in Bayern. Forstwiss. Cbl. 79: 17—42.

TAMM, C.O. et al. 1974. The optimum nutrition experiment Stråsan. A brief description of an experiment in a young stand of Norway spruce (*Picea abies* Karst.). Research Notes, Dept. Forest Ecology and Forest Soils No. 17.

TUKEY, H.B. 1970. The leaching of substances from plants Ann. Rev. Pl. Phys. 21: 305—324.

VOGL, M. et al. 1972. Untersuchungen zur individuellen Rauch- und Frostresistenz von Fichten aus einem Schadgebiet im oberen Erzgebirge. Archiv Pflanzensch. 8: 233—243.

WEHRMANN, J. 1959. Mineralstoffernährung von Kiefernbeständen (Pinus silv.) in Bayern. Forstwiss. Cbl. 78: 129—150.

ZECH, W. & POPP E. 1983. Magnesiummangel, einer der Gründe für das Fichten- und Tannensterben in NO-Bayern. Forstwiss. Cbl. 102 (in press).

ZÖTTL. H. & KENNEL. R. 1962. Die Wirkung von Ammoniakgas- und Stickstoffsalzdüngung in Kiefernbeständen. Forstwiss. Cbl. 81: 65—91.

Total of 28 references

DISTRIBUTION AND MOBILITY OF BORON IN FOREST ECOSYSTEMS

Bo Wikner

Different parts of Scandinavia receive different amounts of boron with the precipitation. The West Coast of Sweden annually receives 25—40 g/ha, central Sweden around 12 g/ha, and the northern part of the country less than 2 g/ha. Boron lost by rivers is much larger than the input by precipitation. Uppsala (central Sweden) receives around 12 g/ha annually with the precipitation. At the same time 100 g/ha is leached out from the system.

The boron concentration in one year old needles of pine and spruce ranges from 10 to 40 ppm along the West Coast, gradually falling to less than 7 ppm in the very north of Sweden. Old spruce needles contain more boron than young ones. For pine needles the reverse is true — old ones contain less than young ones. The boron concentration in wood is usually less than 10 % of the concentration in one year old needles.

Boron available to plants, usually less than 5 % of the total content, could easily turn unavailable by drought, liming, or N-fertilization. Increasing pH followed by coprecipitations with Al- and Fe-compounds are the main factors behind the fixation of boron in soil. NH_4 makes the coprecipitation more complete, whereas citric acid prevents boron from being coprecipitated.

Boron contents in Scandinavian rocks are lower than in rocks from the rest of Europe. The average concentration in European granites is 10 ppm, while the average in Scandinavian granites is 4 ppm. Rocks with a maritime origin contain more boron than other types. The main part of the boron is found as impurities in the rock-forming minerals.

Introduction

In forestry, the interest in micronutrients and their role in the process of growth has been surprisingly small. A generally accepted point of view has been that the boreal forest soils are of young age, originating from rocks and soils brutally treated by the ice during glacial periods. The result of this process was numerous new soil particle surfaces from which nutrients upon weathering could be available to the roots. Therefore, no deficiency in micronutrients could be expected. However, the boron concentrations in igneous rocks are fairly low, especially in the Scandinavian rocks. Further, a large part of the boron in these rocks is found in the mineral tourmalin — one of the most resistant minerals on earth. Fertilizer experiments with well-ground tourmalin show that this mineral is of no interest in plant nutrition (Berger and Truog 1940). Boron deficiency is therefore to be expected where treatments leading to a decrease in boron uptake are undertaken.

Boron in precipitation

Boric acid and the majority of the borates are like sodium ions and chlorides very soluble in water and pass rapidly through most soils. Thus, the oceans have become the main reservoir for boron, and an accumulation of boron is steadily going on in the marine sediments on the ocean floors. The mean boron concentration in the ocean water is about 4.6 ppm according to Bowen (1966). Boron is carried back to land with the precipitation and distributed almost in the same manner as chloride. The ratio of B/Cl is not constant. Since boron is carried more easily than chloride in the air, this ratio increases with the distance from the coast, that is with decreasing maritime influence. Iodine and boron have similar distribution patterns. The annual deposition of boron is in Denmark 30 g/ha (Jensen 1962), in Poland 24—42 g/ha (Chojnacki 1968), in Germany 10—170 g/ha, usually around 30 g/ha (Riehm et al. 1965), in France 13—30 g/ha (Chabannes 1959), and

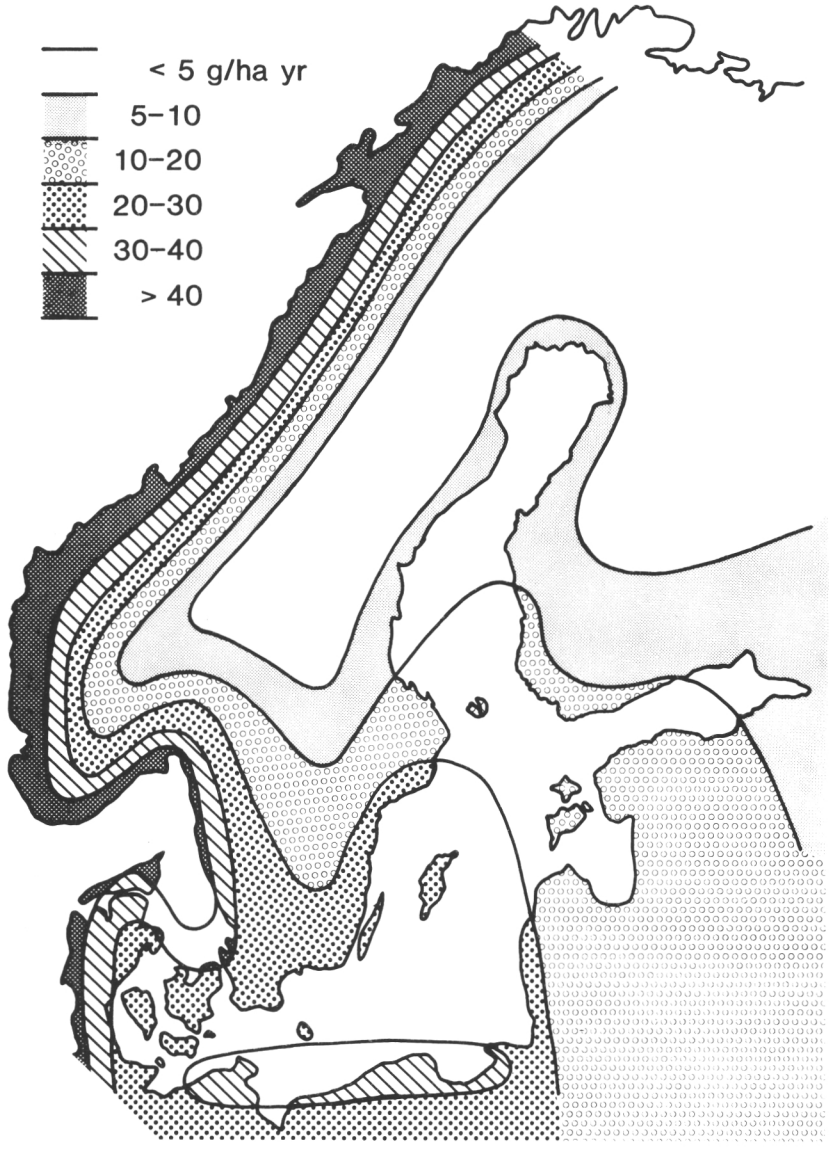


Figure 1. The annual deposition of boron in the north of Europe.

in Sweden (Uppsala, a few km north of Stockholm) 12 g/ha (Philipson 1953). My own measurements, done according to Wikner (1981), show that the West Coast of Sweden annually receives 25—40 g/ha, whilst areas of northern Sweden have annual depositions of boron of less than 8 g/ha. Suddesjaur in the province of Norrbotten, northern Sweden, receives only 1—3 g boron per hectar annually. In Garpenberg, in the province of Dalecarlia, the total boron deposition during 1976 was 6 g/ha and during 1977 8 g/ha (Fig. 1).

The boron deposition is larger during the summer than during the winter, and the boron concentration is higher in rain than in snow. Industrial regions have a higher boron deposition due to an extensive use of fossil fuels (Chojnacki 1968). During stormy years, like 1969, the coastal line may receive several hundreds of grams per hectare. This is probably the reason why Stevenhage in

Great Britain during 1969 received around 600 g boron/ha (Statens Naturvårdsverk 1976). Also Japanese figures on boron in snow and rain are surprisingly high (Muto 1956).

Boron in fresh water

Ahl and Jönsson (1972) made and extensive survey on boron in Scandinavian fresh waters. To all appearances much more boron is flushed out with the big rivers than is received with the precipitation (Table 1).

Human activities can lead to an increase in the boron concentrations in the recipients. Perborates in washing powder and boron fertilizers are the main sources. Since the total consumption of boron in Sweden in 1969 (IVA rapport 1970) was only 600 000 kg of boron and the boron released and spread from fossil fuels 190 000 kg (Statens Naturvårdsverk 1976), this cannot, however, explain the relatively large discrepancy between boron added by precipitation and boron lost to the oceans with the river water. There seems to be rapid depletion of boron from all soils, but especially from those of maritime origin. The process has been accelerated due to acid precipitation.

Figure 1 shows the estimated annual deposition of boron in Scandinavia. It has been assumed that the distribution patterns is similar to that of chloride. Figure 2 shows the concentration of boron in fresh waters of Norway and Sweden according to Ahl and Jönsson (1972). The average concentration of the world river water is 0.013 ppm (Bowen 1966). Further studies on this subject are of great importance. From what sites is boron liberated? Does clear cutting of forests contribute to the increased leaching, and if that is correct, could boron deficiency be one of the factors behind the difficulties to generate new forest in deforested areas in the north of Sweden.

Boron in rocks

The geochemistry of boron is complicated. Unsatisfactory analytical determination methods have made it impossible to form a clear picture of the behaviour of boron in rocks and during rockforming processes. Thanks to the works by Landergren (1945), Harder (1959a, b, 1961), Sahama (1945), and Goldschmidt and Peters (1932) it is today possible to understand the main paths in the geochemistry of boron. Boron is found in rocks in many different minerals, among which tourmalin is the most important. Tourmalin is a very resistant mineral, which cannot be dissolved, even in hydrofluoric acid. Also, during many rockforming processes tourmalin remains unchanged. The mineral is thus useless as a boron source for plants. A better boron source is the large part of the boron which is found as "impurities" in many common minerals. In general, igneous rocks are poor in boron, while rocks of maritime origin contain more. Basic, calcareous, and volcanic rocks are usually very poor in boron (Table 2). The distribution of boron in igneous rocks is uneven. In massives of granite boron seems to be enriched in the parts which were coldest during the metamorphosis, that is, in the margins of the granitic bodies.

Igneous rocks of Scandinavia have in general very low boron concentrations. Granites in Rosslagen contain about 4 ppm

Table 1. Boron annually added by precipitation in relation to the annual loss of boron with river water recalculated as a loss from the area and expressed in g/ha.

River	Station	Boron added by precipitation, g/ha	Boron lost with river g/ha[1)]	Remarks
Ume älv	Stornorrfors	4—8	21	
Ångermanälven	Sollefteå	4—8	28.1	
Dalälven	Näs bruk	5—9	41.3	
Fyrisån	Kuggebro	10—18	99.7	Sediments of
Göta älv	Trollhättan	15—35	41.5	maritime origin

1) Ahl and Jönssön (1972)

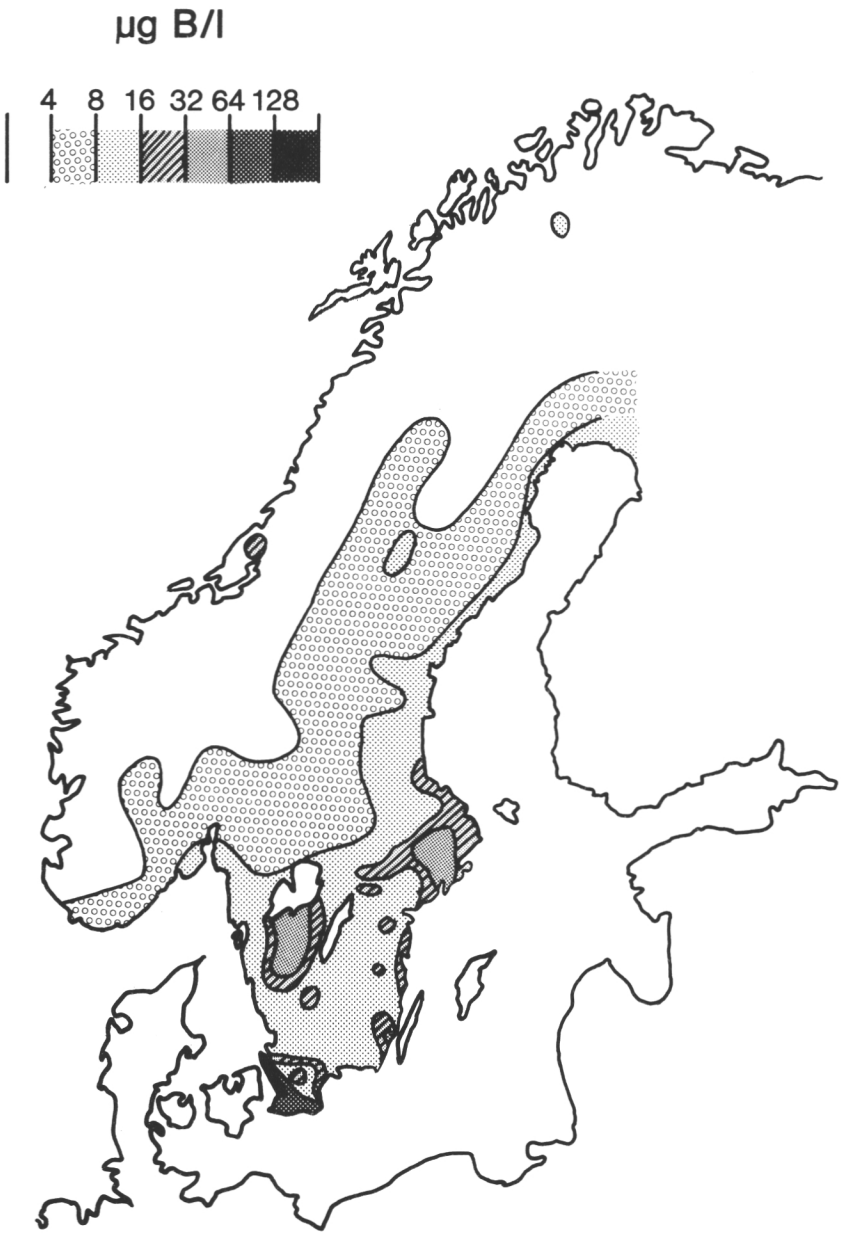


Figure 2. The concentration of boron in Scandinavian fresh water according to Ahl and Jönsson (1972).

(Lundegårdh 1947), granites from southern Norway 0.2—0.8 ppm (Landmark 1944), and granites from Finland 1—3 ppm (Sahama 1945).

According to Harder (1959a, b, 1961), a probable mean value for granites of the world is 10 ppm. Boron in gneisses varies between 1 ppm and 50 ppm. The gneisses seem to be somewhat richer than the granites in Scandinavia. Especially paragneisses often reach 50 ppm. Quartzites are richer than granites in boron. Unfortunately, a major part is found as tourmalin.

Table 2. Boron content in different rocks (ppm)

Rock	B content	Reference
Igneous rocks, average	13	Green (1959)
Igneous rocks, ultrabasic	40	Vinogradov (1956)
Igneous rocks, basic	10	Vinogradov (1956)
Igneous rocks, acid	15	Vinogradov (1956)
Granites	15	Vinogradov (1962)
Diorites and andesites	15	Vinogradov (1962)
Basalts and gabbros	5	Vinogradov (1962)
Dunites	1	Vinogradov (1962)
Earth's crust, average	10	Goldschmidt and Peters (1932)
Igneous rocks, average	10	Taylor (1964)
Shales	100	Turekian and Wedepohl (1961)
Sandstones	35	Turekian and Wedepohl (1961)
Limestones	20	Turekian and Wedepohl (1961)
Coal	100	Rankama and Sahama (1950)
Earth's crust	10	Andrew-Jones (1968)
Igneous rocks	13	Andrew-Jones (1968)
Sediments, average	56	Andrew-Jones (1968)
Limestone and dolomite	18	Krauskopf (1956)
Sandstones	155	Krauskopf (1956)
Shales	130	Green (1959)
Earth's crust, average	50	Vinogradov (1959)

The boron geocycle

The ocean is the starting point for the formation of boron-containing rocks. Boron is strongly absorbed by clay minerals especially by illite, on the ocean floor. The boron absorption by clays is proportional to 1) the boron concentration in the solution, 2) the particle size of the clay, 3) the salinity, and 4) the temperature.

The boron-absorbing capacity of illite is much higher in saline water than in fresh water. A high temperature hastens the reaction.

The marine sediments with their high boron concentrations (around 220 ppm) could turn to sedimentary rocks and slates (mean boron concentration 100 ppm). Scandinavian sandstones usually have low concentrations of boron (around 30 ppm). There are plenty of exceptions, however. Since sand does not absorb any boron during sedimentation, we will find most of the boron as tourmalin.

Upon metamorphosis and palingenesis boron is lost, especially at high temperatures. It can be transported by water vapour or as volatile boric acid. The circumstances determine whether boron will be trapped and forced into tourmalin formation or lost to the nearest environment. On the whole, the formation of igneous rocks leads to a further drop in the boron concentration (to around 10 ppm). The boron content will decrease further if igneous rocks are re-metamorphosed. Thus gneiss granites are extremely poor in boron (around 2 ppm). Gneisses with a marine clay sediment origin (paragneisses) sometimes contain more than 100 ppm of boron.

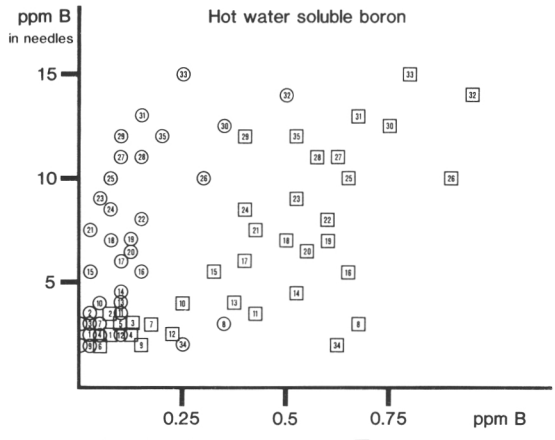
Weathering is the last chain in the boron geocycle, which brings the boron back to the oceans. Chemical weathering causes an increase in the tourmalin content since this mineral is exceedingly resistant. The fraction of boron earlier described as "impurities" should decrease gradually.

Boron in soils

From a nutritional point of view, boron could be divided into four fractions:

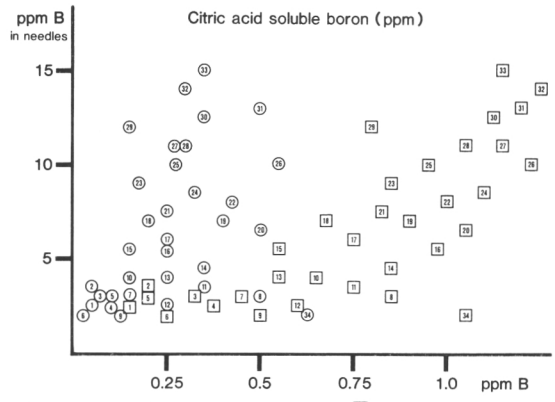
a) Totally unavailable boron (chiefly tourmalin)
b) Unavailable boron (impurities in feldspars and quartz
c) Temporarily unavailable boron (boron in micas, illite, sesquioxides and undecomposed organic matter)
d) Available boron (usually regarded as equal to hot water soluble boron according to Berger and Truog 1939)

Figure 3 shows the relationship between hot water soluble boron in soils and the concentration of boron in pine needles. The



Organic layer A_0—A_1 .....□
B_2-horizons of the mineral soil .....○

Figure 3. The relationship between hot water soluble boron in forest soils according to Berger and Truog (1940), and the corresponding concentration of boron in one year old pine needles.



Organic layer A_0—A_1 .....□
B_2-horizons of the mineral soil .....○

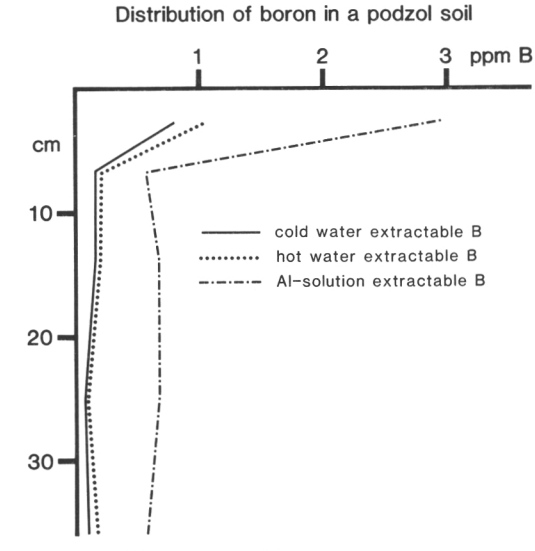
Figure 4. The relationship between citric acid soluble boron and the corrsponding concentration of boron in one year old pine needles.

analyses were performed according to Wikner and Uppström (1980). In Figure 4 citric acid (0.1 M) was used as an extractant. (One hour extraction time, 10 g of soil in 50 mL). Citric acid soluble boron values in the Ao layers seem to correlate quite well with the boron concentrations in pine needles.

A typical podzol profile and the distribution of boron throughout the profile are illustrated in Figure 5. The different layers were: Ao 0—4 cm, A_2 4—8 cm, B_2 8—18 cm, and B_3 18—30 cm. Note that the B_2 horizons usually contain very little water-soluble boron. Stronger extractants reveal that the B_2 layers have a certain boron-fixing ability. Boron is fixed to the sesquioxides and is only to some extent available to plants.

It is, however, very hard to judge from soil analyses how much boron is actually available. "Available boron" sometimes becomes unavailable because of drought. On the other hand, with an increased microbiological activity and a steady production of acid extractants from roots, temporarily unavailable boron could be released. If these favourable conditions are combined with a steady supply of water, the boron uptake by plants will be better than could be expected from the analytical figures.

Therefore, soil analyses of boron have a limited value in the diagnosis of boron deficiency. Table 3 shows the results obtained



——— Cold water extractable boron (Soil: Water 1:5, extraction time 6 hours)
..... Hot water soluble boron according to Ahl and Jönsson (1972)
..... Ammonium lactate — acetic acid extractable boron (Soil: Extractant 1:5, extraction time 6 hours)

Figure 5. The distribution of boron throughout a typical podzol profile

from the fertilizer experiment plot area at Gimo (110 km N Stockholm) owned by Korsnäs Marma AB. Needle analyses of last year's needles in the upper part of the pine crowns clearly show that the uptake of boron has decreased dramatically after ferti-

Table 3. The fertilizer experiment at Gimo.

	Plot nr						
	1	2	3	4	5	6	7
	N kg/ha						
	0	360	240	600	180	120	480
B in neddles (ppm)	7.9	5.0	6.7	6.5	5.1	6.1	3.5
Total B in Ao (ppm)	2.6	1.5	2.0	1.9	1.5	1.9	1.0
Hot water B in B_2	0.24	0.20	0.22	0.22	0.23	0.22	0.21
Volume growth (m^3/ha) during 5 yrs.	0	6.2	9.0	11.0	8.2	6.3	16.6

Table 4. Boron concentration (ppm) in an aqueous solution before and after precipitation of Al and Fe.

pH-raising component	0.1M $FeCl_3$	0.1M $AlCl_3$	0.1M $FeCl_3$ 0.1M citric acid	0.1M $AlCl_3$ 0.1M citric acid	0.1M $AlCl_3$ 0.1M $FeCl_3$
—	1.0	1.0	1.0	1.0	1.0
NH_3	0.5	0.02	1.0	0.99	0.10
$Ca(OH)_2$	0.60	0.30	0.99	0.99	0.50

lization with nitrogen. The boron concentration in the needles decreases with an increased application of nitrogen. Consequently, it was found that the total boron concentration in the organic layers of fertilized plots had decreased. The "available boron" in the mineral soil did not show any significant decrease. Since the drop in needle boron concentration cannot be fully explained by the dilution effect, the question arises: "Why do fertilized trees take up less boron than unfertilized trees?

It is obvious that a large application of nitrogenous fertilizer, through antagonism, makes it difficult for the roots/trees to take up boron, the result of which is decreasing boron concentrations in the needles. Hence, the litter will be poor in boron, and soon or later we will find the whole organic layer poor in boron. Meanwhile, the boron in organic matter originating from litterfall before fertilization has to a great extent been mineralized and leached downwards the soil profile. If the roots no longer retain boron, this portion of boron could be lost from the biocirculation if not fixed by sesquioxides in the iron-rich B_2-horizon of a podzol-profile.

The mechanism of boron fixation in soil is not fully understood, but most likely the OH-groups in the organics and in the sesquioxides are the fixing points. To be able to fix boron, these OH-groups should be placed like in a diol of cis-configuration, and the environment pH should not be too acidic. The OH-groups of sesquioxides seem to have a favourable position for boron binding.

In the past, a method to concentrate trace elements in water consisted of introducing aluminium chloride or ferric chloride in a large water sample. Upon an increase in pH, these salts precipitate as more or less jelly-like water-containing oxides. Trace elements are successfully concentrated by coprecipitation. The method is used on a large scale in sewage works to eliminate phosphates from water.

To find out if this type of precipitation reaction is capable of coprecipitating also boric acid, we performed some simple experiments with water samples containing 1 ppm of boron and 0.1 M aluminium chloride $(AlCl_3(H_2O)_3$ and $FeCl_3 \cdot 3H_2O$ respectively. pH was set to 4 by HCl. Two bases, ammonia and calciumhydroxide, were chosen to raise the pH. In some cases citric acid and oxalic acid were added. The results presented in Table 4 clearly indicate that the coprecipitation with iron and aluminium (at pH 5—6) is an important factor making boron unavailable upon liming. The abundance of NH_4^+ increases the coprecipitation of boron.

Citrate and oxalate (good complex bindners to boron, aluminium, and iron) hindered the reaction completely. This ability of some organic hydroxy acids to form

soluble complexes with boric acid is probably of greater significance in plant nutrition than earlier assumed. Citric acid and oxalic acid are found in exudates produced by roots. Since these acids also form soluble complexes with aluminium, iron, and many other metals, they are very important in the process of dissolving sesquioxides — the main reservoir of boron during droughts when the organic layer no longer can supply the plants/trees with boron. Thus, boron deficiency in natural forests could be expected mainly on soils lacking a well-developed B_2-horizon. However, liming or N-fertilizing could easily change the mechanisms of boron uptake. There are reasons to suspect that a N-fertilization will give rise to a decreased production of root exudates (sugars, citric and oxalic acid, vitamins, etc.), which is well reflected in a drop in microbiological activity in the root zone.

Another question regarding the biocirculation of boron in forests is the speed of circulation. A very limited amount of boron can, if the circulation is fast, do the same degree of biochemical work as a larger amount of boron. A fast turn-over of boron is favoured by a good water factor, a high microbiological activity, a well-established root system, a high temperature, good aeration in soil, and active roots producing exudates. The increased mobility can, however, lead to losses by leaching if the root systems die or are nonfunctional. This could easily happen in connection with clear cutting (Amazonas), and possibly with N-fertilization.

Scandinavian rocks are poor in boron and consequently the soils are also poor in boron. Extensive leaching has depleted the soils further. Boron deficiency in forest trees occurs most likely on:

1) Fresh water sediments
2) Nutrient-poor bogs
3) Soils susceptible to drought
4) Soils with a very thin A_o layer
5) Soils which do not allow the roots to grow deep enough (waterlogged soils, heavy soils, etc.)
6) Fertilized or limed soils
7) Soils with a minimum of maritime influence.

Boron in plants/trees

It is well known that monocots contain less boron than do the dicots. Among the monocots, grasses have extremely low demans — vegetative growth could be performed without boron (Shkolnik 1939), and the concentration in leaves is very low (1—2 ppm). Conifers, on the other hand, have a higher demand and consequently higher concentrations in the needles (1—50 ppm), in Sweden usually 5—20 ppm. The concentration changes from year to year and from month to month (Fig. 6) and is different in different parts of the tree. The main rule for plants in general is that boron tends to accumulate in the leaves, leading to higher concentrations in old leaves. The two genera *Pinus* and *Picea* show different distributions of boron in the needles. Young pine needles show higher concentrations than old ones while spruce needle concentration increases with needle age. Pines seem to have the extraordinary ability to translocate boron from old needles to buds and young needles.

The boron concentration in trees decreases with decreasing maritime influence. Figure 7 shows the concentration of boron in one-year-old Norwegian spruce needles from old stands on moraine from different parts of Sweden.

The distribution of boron in a forest stand is found in Table 5. Biomass and nitrogen values were earlier calculated by Nyqvist. Both total and hot water soluble boron in soil are accounted for.

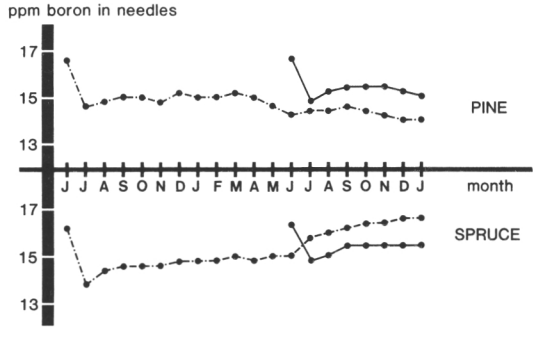


Figure 6. The variation of boron concentration in pine and spruce needles with time.

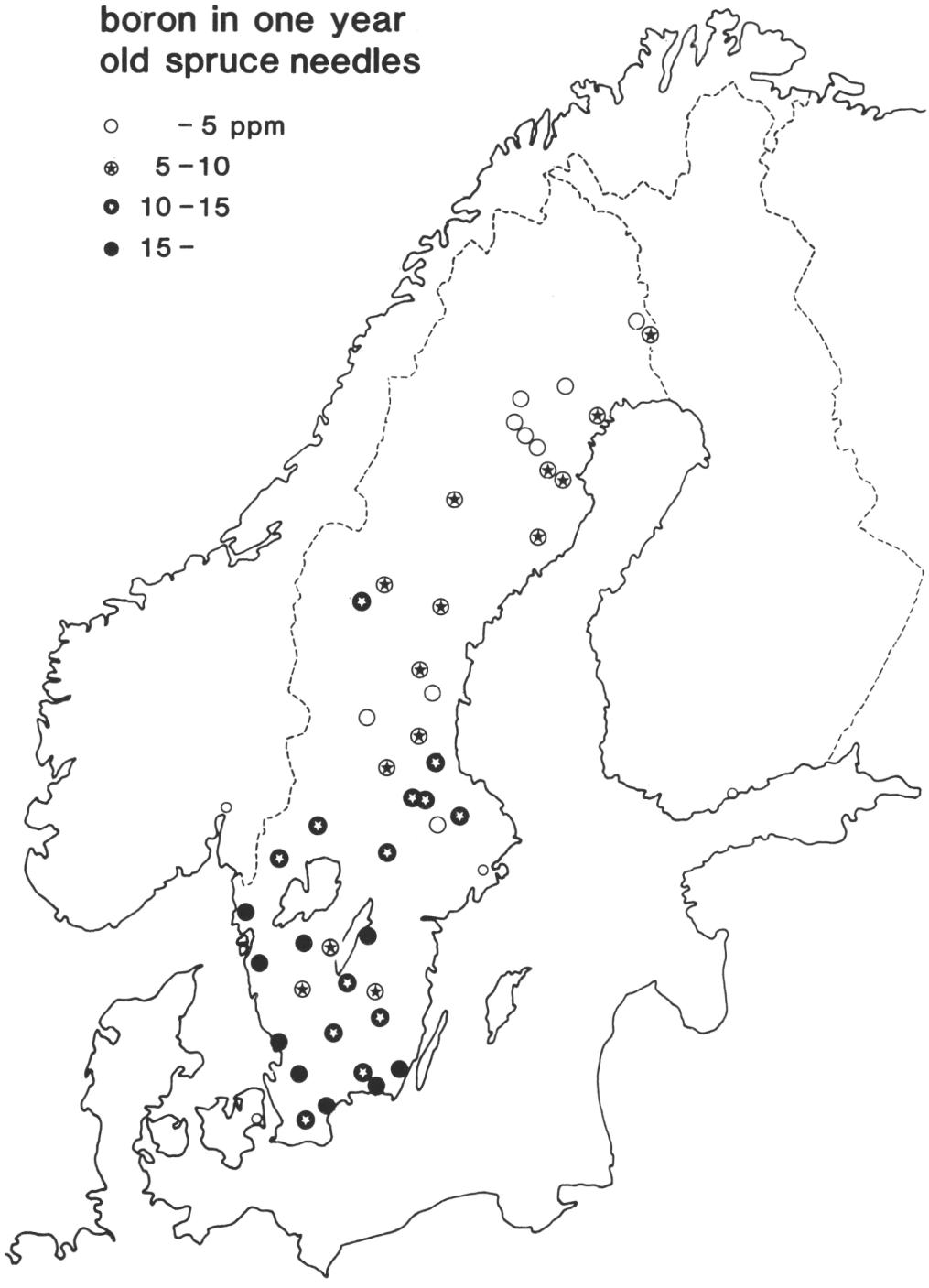


Figure 7. The mean boron concentration in one year old spruce needles from mature stands on morain soils from different parts of Sweden.

Table 5. Distribution of boron in a forest stand.

	Biomass ton/ha	Boron ppm	Boron g/ha	Nitrogen kg/ha
Wood	110	2	220	64
Bark	9	8	72	33
Twigs > 20 mm	7	3	21	11
Twigs 5—20 mm	8	4	32	22
Twigs < 5 mm	6	6	36	43
Needles	12	12	144	122
Dry twigs	1	4	4	3
Sum:	153		529	298
Stumps	17	2	34	13.9
Roots > 20 mm	3	5	15	6
Roots 20—5 mm	3.5	5	17.5	12.9
Roots 5—2 mm	1.4	7	9.8	8.1
Roots < 2 mm	1.3	9	11.7	10.1
Roots in mineral soil	2.4	6	14.4	14
Sum:	28.6		102.4	65
Vaccinium myrtillus	0.187	15	2.81	1.97
Vaccinium vitis-idaea	0.004	10	0.04	0.04
Deschampsia flexuosa	0.060	4	0.24	1.07
Luzula pilosa	0.003	5	0.02	0.06
Other herbs	0.016	20	0.32	0.31
(Mosses):	(0.524)	(6)	(3.14)	
Sum exc. mosses:	0.27		3.46	3.45
Soil: S-layer	8.9	11 (1.2)	98 (11)	112
F-layer	25.1	9 (1.0)	226 (25)	366
H-layer	69.8	9 (1.1)	628 (77)	681
Sum:	103.8		952 (113)	1159
0— 5 cm	327	15 (0.3)	4905 (262)	722
5—10 cm	361	13 (0.04)	4693 (144)	469
10—15 cm	354	10 (0.1)	3540 (35)	454
15—20 cm	366	12 (0.01)	4392 (37)	384
20—25 cm	390	13 (0.15)	5070 (59)	426
25—30 cm	455	15 (0.15)	6825 (68)	483
30—35 cm	400	12 (0.1)	4800 (40)	284
35—40 cm	417	12 (0.1)	5004 (42)	259
40—45 cm	426	10 (0.05)	4260 (21)	209
Sum:	3496		43489 (708)	3690

Literature

AHL, T. & JÖNSSON, E. 1972. Ambio 1 nro 2.

ANDREWS-JONES, D.A., 1968. Mineral Ind.Bull 11, nr 6,31.

BERGER, K. C. & TRUOG, E. 1939. Ind.Engin. Chem. 11(10): 540—545.

— & TRUOG, E. 1940. J.Am. Soc. Agron. 32: 297—301.

BOWEN, H. J. M. 1966. Trace Elements in Biochemistry, Academic Press. London 1966.

CHABANNES, J. 1959. Chim. et Industri 82: 835—837.

CHOJNACKI, A. 1968. Pamietnik Pulawski 35: 163—172.

GOLDSCHMIDT, W.M. & PETERS, Cl. 1932. Zur Geochemie des Bors. Teil I und II. Nachr.Ges.D. Wiss.Math. — Phys K1 Göttingen 1932.

GREEN, J. 1959. Geol.Soc.Am.Bull. 70: 1127—1184.

HARDER, H. 1959a—b, 1961. Beitrag zur Geochemie des Bors Teil I, II und III. Nachr.Akad.Wiss. Göttingen 11 match. -Phys K1, Göttingen 1959, 1959 and 1961.

IVA rapport 33 "Bor från miljösynpunkt". Stockholm 1970.

JENSEN, J. 1962. Tidskr.Pl.Avl. 65: 894—906.

KRAUSKOPE, K. B. 1956. Econ.Geology 50th Ann.Vol. 411—463.
LANDERGREN, S. 1945. Arkiv för kemi, Min.Geol. 19A: 1—31.
LANDMARK, K. 1944. Bergens Museums Årsbok nro 5: 1—20.
LUNDEGÅRDH, P. 1947. Ark. Kem. Min. Geol. Bd 23A, Nro 9: 1—160.
MUTO, S. 1956. Bull. Chem.Soc. Jap. 29: 532—536.
NYQVIST, N., Mimeo
PHILIPSON, T. 1953. Acta Agric. Scand. 3: 121—242.
RANKAMA, K. & SAHAMA T. G. 1950. Geochemistry Chicago Univ. Press. Chicago 1950.
RIEHM, H., QUELLMALZ, E. & KRAUS, M. 1965. Zentralbl. biol. Aerosol Forsch 12(5).
SAHAMA, T. 1945a—b. Bull.Comm.Geol. Finlande 135 and 136.
SHKOLNIK, M.Ya. 1939. Izv Akad. Nauk SSR.
Statens Naturvårdsverk, Publikationer 1976: 7.
TAYLOR, S. R., 1964. Geochim. Cosmochim. Acta 28. 1273.
TUREKIAN, K. K. & WEDEPOHL, K. H. 1961. Bull.Geol. Soc. Am. 72: 175.
VINOGRADOV, A. P. 1956. Geochemistry 1: 1—43.
— 1959. The geochemistry of rare and dispersed chemical elements in soils. Consultants Bureau, New York 1959.
— 1962. Gekhimiya 7: 555.
WIKNER, B. & UPPSTRÖM, L. 1980. Comm.Soil Sci. Plant. Anal. 11(1): 105—126.
— 1981. Comm. Soil Sci. Plant Anal. 12: 697—710.

Total of 31 references

6-PHOSPHOGLUCONATE DEHYDROGENASE ACTIVITY IN SCOTS PINE VEGETATIVE BUDS ON A GROWTH DISTURBANCE AREA

Pekka Pietiläinen

The purpose of this study was to elucidate the role of boron and 6-phosphogluconate dehydrogenase in the regulation of pentose phosphate shunt activity in Scots pine vegetative buds. The experimental material consisted of vegetative buds from NPK-fertilized phenotypically normal and growth disturbance pines and ash fertilized pines from Muhos (65°52'N, 26°07'E).

The interaction of 6-phosphogluconate dehydrogenase with boron was determined from the crude enzyme fraction of the buds.

The enzyme activities of the phenotypically normal and growth disturbance pines were higher than the enzyme activity in the ash fertilized pines.

Physiological concentrations of 5 ppm, 10 ppm and 15 ppm of orthoboric acid showed marked inhibitory effects on the 6-phosphogluconate dehydrogenase activity of crude enzyme fraction.

Introduction

On drained peatlands tree growth is stimulated by applying macronutrients (N, P and K) to peatland sites originally poor in nutrients (Lukkala 1955, Kaila 1956, Huikari and Paarlahti 1967, Huikari and Paavilainen 1972, Kurki 1972, Paavilainen 1979). The amounts of the applied nutrients depend on the nutritional status of the peatland site (Huikari 1952, Heikurainen 1971, Paavilainen 1979). However, sooner or later micronutrients may become a factor limiting tree growth (Hearman 1938, Prevot and Ollagnier 1961, Paavilainen 1969, 1980, Bussler 1974, Huikari 1974, Tolonen 1974, Sillanpää 1975, Veijalainen 1977, Kolari 1979) and result into growth disturbances (Veijalainen 1975, Raitio and Rantala 1977, Kolari 1979).

Most of the growth disturbances in Scots pines appear on deserted agricultural peatlands, naturally leached acidic soils and especially on mire centre effect peatlands after forest improvement measures (Veijalainen 1978, Kolari 1979, Silfverberg 1979). The first visible signs of growth disturbance are the malformation of the buds, which result into retardation of growth and shoot dieback in the apical portions of the pines. After repeated shoot dieback the appearance of the Scots pine becomes bushy (Veijalainen 1975, Raitio and Rantala 1977, Kolari 1979).

Needle analyses (Stoate 1950, Smith 1962, Paarlahti et al. 1971, Driessche 1974) have revealed that macronutrient fertilization induces a micronutrient dilution effect (Prevot and Ollagnier 1961, Veijalainen 1977) which can continue without visible growth disturbances (Bussler 1974, Raitio and Rantala 1977). It is noteworth that the macronutrient (N, P, PK and NPK) fertilization treatments have interactions with the micronutrients and lower the foliar micronutrient contents in plants. For example PK- and NPK-fertilization combinations decrease the Scots pine's foliar boron (B) content even to such an extent that the effect of NPK-fertilization differs significantly from those of phosphorus (P) and potassium (K) (Bingham et al. 1958, Schütte 1959, Bingham and Garber 1960, Appleton and Slow 1966, Bradford 1966, Albrektson et al. 1977, Veijalainen 1977, Braekke 1979).

The antagonistic effect on micronutrients i.e. the decrease of the foliar micronutrient content, resulting from macronutrient fertilization may occur in the soil, in the root (nutrient absorption) (Puustjärvi 1956, 1973) and in the plant (distribution of the nutrients to functional sites and nutrient mobility within the plant) (Olsen 1972). Nevertheless it is evident that plain macronutrient fertilization induces nutritional changes in plants and enhances nutritional disorders which result into susceptibility of abiotic and biotic damages that arise from unbalanced metabolic activities (Koskela 1970, Epstein 1972, Gauch 1972, Levitt 1972, Keller 1973, Bussler 1974, Nicholas and Egan 1975, Veijalainen 1977, Braekke 1979, Aronsson 1980).

Purpose

The purpose of the study was to determine the effect of boron on the 6-phosphogluconate dehydrogenase activity of the vegetative buds of Scots pine from NPK-fertilized growth disturbance area.

Materials and methods

Vegetative buds

Vegetative buds of Scots pine were collected from three different trees monthly on the following dates: 4th September 1978, 4th October 1978, 2nd November 1978, 20th January 1979, 9th February 1979, 5th March 1979, 4th April 1979 and 2nd May 1979 from a forest fertilization experiment at Muhos (65°52'N; 26°07'E). The small sedge open peatland was drained in 1933 and the pine seeds were sown in 1934. The stand was fertilized with 200 kg/ha Urea (46 % N) and 500 kg/ha of Peatland Forest Fertilizer (10 % P—12 % K) in 1971. The ash fertilization 10 000 kg/ha was carried out in 1972. The height of the stand was 3—5 m in 1978. Boron deficiency symptoms were encountered in the study area, but their relative frequencies were not studied throughly and with the aid of foliar nutrient analysis it was confirmed that there was a boron deficiency in the study area. Since there were no means to study the whole scale of the end products it was decided to study 6-phosphogluconate dehydrogenase activity in the vegetative buds according to Lee's and Aronoff's (1967) hypothesis.

The buds were collected monthly from the upper two thirds of the crown of the ash fertilized, NPK-fertilized phenotypically normal and NPK-fertilized growth disturbance pines (all together from 72 pines). The buds scales were removed. The remaining tissue was stored at —21°C in small plastic bags and used later for enzyme activity measurements.

The stored frozen vegetative buds were thawned and 0,5 g of buds were weighed and ground for 10 min in a mortar with 1,0 g of sea sand and 10 ml of tris- HCl buffer of pH 7,6 in an ice bath. The obtained homogenate was pressed through a gauze. A turbid solution thus obtained was centrifuged at 12 000 g for 15 min at 4°C. The supernatant was tested for enzyme activity as was the resuspended and recentrifuged (12 000 g) pellet. The 6-phosphogluconate dehydrogenase activity was high in the supernatant and very low in the pellet. The grinding time of the buds was obtained by measuring activities of the recentrifuged pellet supernatants. After 10 min grinding the 6-phosphogluconate dehydrogenase activity was negligible (modified from Sagisaka 1972, 1974).

Enzyme activity measurements

Triplicate 6-phosphogluconate activity measurements were done from each trees bud sample. The 6-phosphogluconate dehydrogenase assay was carried out by conventional spectrophotometric methods as follows: The reaction mixture contained 2,6 μ moles of $NADP^+$, 30 μ moles of $MgCl_2$ and 0,5 μ moles of 6-phosphogluconate, 150 μ moles of tris-HCl buffer of pH 7,6 and the bud supernatant (crude enzyme) 0,5 ml, in a total volume of 4,0 ml. The absorbance of the crude enzyme was measured in a Hitachi spectrofotometer 100—40 at wavelength 340 nm against a blank, which was composed of the same reagents except the crude enzyme (modified from Sagisaka 1972, 1974).

The relative enzyme activity in the crude enzyme was expressed as the evolution of $NADPH + H^+$, which

has an absorption change after reduction at wavelength 340 nm.

The crude enzyme of the buds that were collected in September was tested for boron and 6-phosphogluconate dehydrogenase interaction in the preciously described reaction mixture with 5 ppm, 10 ppm and 15 ppm boron consentrations. Three parallel spectrophotometric measurements were carried out as described above from the bud collected in September.

Results

Crude enzyme and boron interaction

The crude enzyme was tested for boron and 6-phosphogluconate dehydrogenase interaction as described in materials and methods.

In the ash fertilized trees the foliar boron was 38,1 μg/g dry weight. As boron was added to the reaction mixture there was an inhibitory effect on the enzyme activity. The inhibitory effect was stronger with higher boron concentrations (Fig. 1)

When boron was added to the crude enzyme of NPK-fertilized phenotypically normal pine bud extracts an inhibitory effect occurred. The foliar boron of the normal looking pines was 2,9 μg/g dry weight. Noteworth was that the enzyme activity of the buds was twice of that of the ash fertilized trees and that 10 ppm of boron had to be added before a notable inhibition took place (Fig. 2).

The enzyme activity of NPK-fertilized growth disturbance pine buds was somewhat lower than in the ash fertilized tree buds. The inhibitory effect of boron was stronger than in the ash fertilized tree buds (Fig. 3). The foliar boron was 2,1 μg/g.

The enzyme activity of the vegetative buds from the phenotypically normal tree shows that there was much more pentose phosphate shunt activity than in the ash fertilized and growth disturbance tree bud extracts and indicate higher substrate concentrations.

In the interpretation of the results one must bear in mind that there was strong variation in the results obtained when the effect of boron was tested on the crude enzyme. In some cases boron had no effect on the enzyme activity. To obtain more

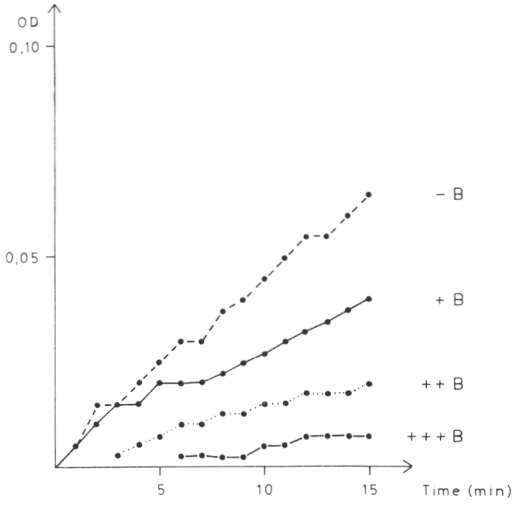


Figure 1. Effect of boron on 6-phosphogluconate dehydrogenase activity of the vegetative buds of ash fertilized Scots pines in September (—B = no boron added, +B = 5 ppm of boron, ++B = 10 ppm of boron, +++B = 15 ppm boron).

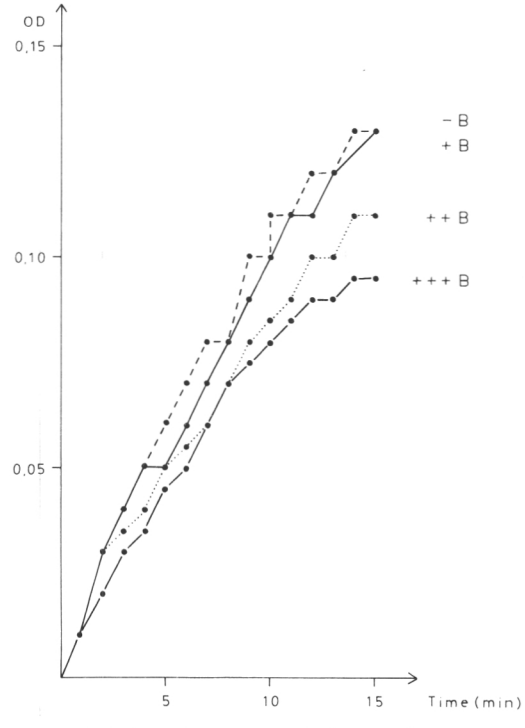


Figure 2. Effect of boron on 6-phosphogluconate dehydrogenase activity of the vegetative buds of phenotypically normal Scots pines in September (—B = no boron added, +B = 5 ppm of boron, ++B = 10 ppm of boron, +++B = 15 ppm of boron).

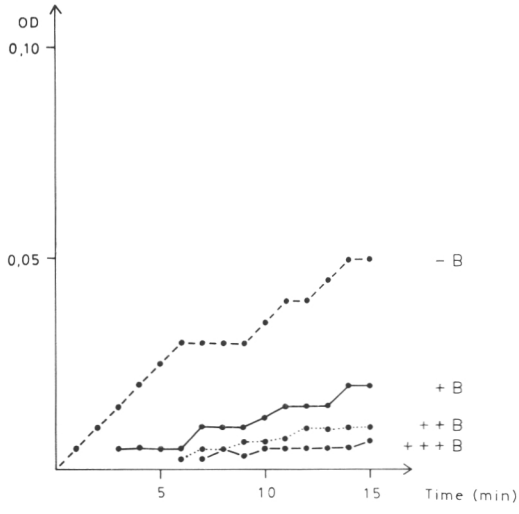


Figure 3. Effect of boron on 6-phosphogluconate dehydrogenase activity of the vegetative buds of growth disturbance Scots pines in September (—B = no boron added, +B = 5 ppm of boron, ++B = 10 ppm of boron, +++B = 15 ppm of boron).

reliable results 6-phosphogluconate dehydrogenase should be purified and then tested for the activity interferences caused by boron. Further more it was interesting that when calcium nitrate was added to the reaction mixture the crude enzyme activities had no uniformity (compare Lee and Aronoff 1967).

Discussion

The metabolism of carbohydrates and the biochemical significance of the pentose phosphate shunt have been reviewed by Gibbs (1959). The pentose phosphate shunt generates NADPH + H^+ and ribose-5-phosphate in the cytosol. NADPH + H^+ is used in reductive biosynthesis and ribose-5-phosphate is used in RNA, DNA and nucleotide coenzymes. Erythrose-4-phosphate is used to synthesise shikimic acid which is an important intermediate in the synthesis of aromatic aminoacids and other aromatic compounds such as phenol derivatives, lignins, indoleacetic acid etc.

Lee and Aronoff (1967) have postulated that boron effects the activity of 6-phosphogluconate dehydrogenase by forming esters with the substrate 6-phosphogluconate. Thus if boron interferes with the activity of the pentose phosphate shunt there should be also effects that are detectable in the end products which utilize intermediates of the shunt in their synthesis.

Rather extensive work has been done on the end products. Johnson and Albert (1967) noted that the first symptoms in boron deficiency is the decrease in RNA content and cessation of tomato root growth. Shkolnik et al. (1961), Shkolnik and Solovjova (1961), Shkolnik (1974), Timashov (1966). Johnson and Albert (1967) have also noticed a decrease of RNA in boron deficient plants. Robertson and Loughman (1974) showed that boron deficiency reduced the rate of incorporation of phosphate into the nucleotides. Hundt et al. (1970) demonstrated the effect of boron deficiency on nucleic acid metabolism and protein synthesis. Coke and Whittington (1968) suggest that necrosis in the growing points of boron deficient plants in caused by auxin accumulation. Shkolnik (1974) also suggests that the accumulation of excess auxins and phenols is the primary cause of necrosis in plants associated with boron deficiency. Rajaratnam and Lowry (1974) have also noticed increased auxin in boron deficient plants.

On of the most common features in boron deficiency is the accumulation of phenol derivatives. Accumulation of chlorogenic acid and caffeic acid have been identified from several plants (Perkins and Aronoff, 1956). Accumulation of coumarine, vanilinic acid and ferulic acid have been identified by Watanabe et al. (1964) and Rajaratnam and Lowry (1974).

Lee and Aronoff (1967) and Walker (1973) have suggested, that boron may form complexes besides with 6-phosphogluconate with the phenolic acids that result from the accelerated pentose phosphate shunt activity. An autocatalytic system may be formed as boron is combined into phenolic compounds to form phenylboric acids. Thus there is less boron for the inhibition of 6-phosphogluconate dehydrogenase and this results into a build up of phenolic compounds through the further accelerated pentose phosphate shunt. Phenylboric acids that are formed from this kind of autocatalytic system form complexes with sugars easier than with boric acid but phenylboric acid can only form a monodiol ester complex bond. Torssell

(1956) has obtained results that supported this postulation. Phenylboric acids have growth regulating activities (Torssell 1956, Odhnoff 1957). Torssell (1956) has also suggested that arylboric acids are very active compounds and that the lipofilic group allows the complex to penetrate the cell membrane.

The enzyme activities were highest in autumn. Thus 6-phophogluconate and boron interaction was studied in crude enzyme supernatants of the three classes of growth disturbance area pines. The results obtained were uniform with those of Lee and Aronoff (1967). In the ash fertilized and the growth disturbance Scots pine buds the enzyme activity was of the same magnitude. The inhibitory effect that was achieved with 5 ppm boron concentration was approximately the same in both cases. The enzyme activity of the buds from phenotypically normal Scots pines was 2—5 times higher than in the others. A clear inhibition was achieved with 10 ppm boron concentration.

The differences in the enzyme activities were not confirmed to any specific metabolic phenomen. It could be speculated that the differences in the enzyme activities resulted from the differences in the natural substrate and/or boron concentrations (Lee and Aronoff 1967). Further more it could have been a result of the autocatalytic boron concerning system postulated by Walker (1973).

It should be stressed that care should be taken with the interpretation of the results since the enzymatic activity studies were done with crude enzyme fractions.

The boron dilution which occurred after the NPK-fertilization was corrected with borate fertilizer (Braekke 1979, Veijalainen 1980).

The results achieved from the metabolism of boron deficient plants are uniform and it is not difficult to correlate the anatomical and phenotypical deficiency symptoms of various plants, to the characteristic metabolic disorders. Unfortunately there is very little work done on the metabolism of boron deficient pines and thus some care should be taken when the deficiency symptoms are compared with metabolic disorders. The phenotypical and anatomical boron deficiency symptoms (Kolari 1979) are analogical with those of other plants. The most frequently encountered macro-symptoms in Scots pines are 1) shoot or tip dieback, 2) bud dieback or disorders, 3) resin flow from shoots or buds, 4) secondary leading shoots, 5) retarded growth, 6) repeated dieback and bushiness, 7) fascicle or lateral bud proliferation, 8) needles are often short or immature at the shoot apices, 9) necrotic at their tips, 10) yellow and shed at apex, 11) thick and distorted. The roots are reduced in size and number (Kolari 1979).

de Lanuza (1966) and Raitio and Rantala (1977) have reported the following microscopical deficiency symptoms in conifers. 1) The apical meristems are abnormal and cavities may be located in the growing points. 2) Hypertrofic cells and cavities are encountered in the transfusion tissue of the needles. 3) The root's primary xylem fails to differentiate and 4) the break down of the central cylinder may occur resulting into cavities.

Summary

The study was carried out to see the effect of boron on 6-phosphogluconate dehydrogenase activity in the regulation of pentose phosphate shunt of Scots pine (*Pinus sylvestris* L.) vegetative buds. The experimental material consisted of vegetative buds from NPK-fertilized phenotypically normal and growth disturbance pines and ash fertilized pines.

An attempt was made to determine the interaction of boron on 6-phosphogluconate dehydrogenase activity in the crude enzyme fraction of the buds.

Noteworth was that the enzyme activities of the buds from phenotypically normal and growth disturbance pines were higher that of the buds from ash fertilized pines.

The interaction of boron on the 6-phosphogluconate dehydrogenase activity was studied with the crude enzyme fraction of the buds that were collected in September. Physiological concentration of 5 ppm, 10 ppm and 15 ppm of boric acid showed marked inhibitory effects on the 6-phosphogluconate dehydrogenase activity of the crude enzyme fraction.

Literature

ALBREKTSON, A., ARONSSON, A. & TAMM, C.O. 1977. The effect of forest fertilization on primary production and nutrient cycling in the forest ecosystem. Silva Fenn. 11(3): 233—239.

APPLETON, E. J. & SLOW L. J. 1966. Nutritional disorders and fertilizer trials in Pinus radiata stands in Waimea Country. Nelson. N. Z. J. For. 11: 185—201.

ARONSSON, A. 1980. Frost hardiness in Scots pine (*Pinus silvestris* L.) II Hardiness during winter and spring in young trees of different mineral nutrition status. Stud. For. Suec. 155: 1—27.

BINGHAM, F. T. & GARBER, R. J. 1960. Solubility and availability of micronutrients in relation to phosphorus fertilization. Proc. Soil.Sci. Soc. Amer. 24: 209—213.

— , MARTIN, J. P. & CHASTAIN, J. A. 1958. Effects of phosphorus fertilization on California soils on minor element nutrition of Citrus. Soil. Sci. 86: 24—31.

BRAEKKE, F. H. 1979. Boron deficiency in forest plantations on peatlands in Norway. Medd. Nor. inst. skogsforsk. 35: 3.

BRADFORD, G. R. 1966. Boron. In: Chapman, H. D. (Ed.) Diagnostic criteria for plants and soils. Univ. California. Div.Agr.Sci., p 33—61.

BUSSLER, W. 1974. Microscopical and microchemical characteristics of deficiency diseases. In: Plant analysis and fertilizer problems. Vol. 1. Proc. 7th Int. Coll. on plant analysis and fertilizer problems. Hannover.

COKE, L. & WHITTINGTON, W. J. 1968. The role of boron in plant growth. IV. Inter-relationship between boron and indolylacetic acid in the metabolism of bean radicles. J. Exp. Bot. 19: 298—308.

DRIESSCHE, R. van. 1974. Prediction of mineral nutrient status of trees by foliar analysis. Bot. Rev. 40(3): 347—394.

EPSTEIN, E. 1972. Mineral nutrition of plants: principles and perspectives. 412 p. New York. John Wiley and Sons Inc.

GAUCH, H. C. 1972. Inorganic plant nutrition. 488 p. Douden: Hutchinson and Ross. Inc.

GIBBS, M. 1959. Metabolism of carbon compounds. Ann. Rev. Plant physiol. 10: 329—378.

HEARMAN, J. 1938. Minor elements and the pine. Aust. For. 3: 24—27.

HEIKURAINEN, L. 1971. Metsänojituksen alkeet. Ylioppilastuki ry. Helsinki.

HUIKARI, O. 1952. Suotyypin määritys maa- ja metsätaloudellista käyttöarvoa silmällä pitäen. Summary: On the determination of mire types especially considering their drainage value for agriculture and forestry. Silva Fenn. 75: 1—22.

— 1974. Hivenravinteet ja puiden kasvu. Metsä ja Puu 11: 28—29.

— & PAARLAHTI, K. 1967. Results of field experiments on the ecology of pine, spruce and birch. Seloste: Kenttäkokeiden tuloksia männyn, kuusen ja koivun ekologiasta. Commun. Inst. For. Fenn. 64(1): 1—135.

— & PAAVILAINEN, E. 1972. Metsänlannoitus. Helsinki. Kirjayhtymä.

HUNDT, I., SCHILLING, G., FISCER, F. & BERGMANN, W. 1970. Investigations on the influence of the micro-nutrient boron on nucleic acid metabolism. Thaer-Arch. 14: 725—737. In: Mengel, K. & Kirkby, E. A. 1979. Principles of Plant nutrition. Worblaufen Switzerland.

JOHNSON, D. L. & ALBERT, L. S. 1967. Effect of selected nitrogen bases and boron on ribonucleic acid content, elongation and visible deficiency symptoms of tomato root tips. Plant physiol. 42: 1307—1309.

KAILA, A. 1956. Phosphorus in virgin peat samples. Maatal. tiet. aikak. kirja 28.

KELLER, T. 1973. The effect of fertilization on metabolism of forest trees. Proc. Intern. symp. Forest. Fertil. Paris 1973: 55—73.

KOLARI, K. 1979. Hivenravinteiden puute metsäpuilla ja männyn kasvuhäiriöilmiö Suomessa. Kirjallisuuskatsaus. Abstract: Micronutrient deficiency in forest trees and dieback of Scots pine in Finland. A review. Folia For. 389: 1—37.

KOSKELA, V. 1970. Havaintoja kuusen, männyn, rauduskoivun ja siperialaisen lehtikuusen halla- ja pakkaskuivumisvaurioista Kivisuon metsänlannoituskoekentällä. Summary: On the occurrence of various frost damages on Norway spruce, Scots pine silver birch and Siberian larch in the forest fertilization experimental area at Kivisuo. Folia For. 78: 1—25.

KURKI, M. 1972. Suomen peltojen viljavuudesta. II. Über die Fruchtbarkeit des finnischen Ackerbodens auf Grund der in den Jahren 1955—1970 durchgeführten Bodenfruchtbarkeitsuntersuchungen. 1972. Helsinki. Yhteiskirjapaino.

LANUZA, J. M. de 1966. Boron deficiency and toxicity in Pinus radiata 399 p. Inst. For. Invest. Exp. Madrid.

LEE, S. G. & ARONOFF, S. 1967. Boron in plants: A biochemical role. Science 158: 798—799.

LEVITT, J. 1972. Responses of plants to environmental stress. 697 p. AP, New York and London.

LUKKALA, O. J. 1955. Maanparannusaineet ja väkilannoitteet metsänojituksen tukena. Summary: Soil improving substances and fertilizers as on aid to forest drainage. Metsätal. aikakausl. 6—8: 1—5.

NICHOLAS, D. J. D. & EAGAN, A. R. (Eds.) 1975. Trace elements in soil-plant-animal systems. 417 p. New York Academic Press Inc.

ODHNOFF, C. 1957. Boron deficiency and growth. Physiol. plant. 10: 984—1000.

OLSEN, S. R. 1972. Micronutrient interactions. In: Mortvedt, J. J. et al. (Eds.). Micronutrients in agriculture, Madison, USA, p. 242—264.

PAARLAHTI, K., REINIKAINEN, A. & VEIJALAINEN, H. 1971. Nutritional diagnosis of Scots pine stands by needle and peat analysis. Seloste: Maa- ja neulasanalyysi turvemaiden männiköiden ravitsemustilan määrityksessä. Commun.Inst. For. Fenn. 74(5): 1—58.

PAAVILAINEN, E. 1969. Juuristojen ja kasvualustan hivenainepitoisuuksien välisistä suhteista suometsissä. Summary: On the correlation between the contents of trace elements in the roots and growth substratum in certain peatland sites. Suo 20(2): 25—29.

— 1979. Metsänlannoitusopas. Yliopiston kirjapaino. Helsinki.

— 1980. Tuloksia vanhoista tuhkalannoituskokeista. Muhoksen tutkimusaseman tiedonantoja. 20: 20—23.

PERKINS, H. J. & ARONOFF, S. 1956. Identification of the blue-fluorescent compounds in boron deficient plants. Arch. Biochem. Biophys. 64:

506—507.
PREVOT, P. & OLLAGNIER, M. 1961. Law of the minimum and balanced nutrition. In: W. Reuther (ed.). Plant analysis and fertilizer problems. Amer. Inst. Biol. Sci. Pub. no. 8. Washington, D.C. p. 257—277.
PUUSTJÄRVI, V. 1956. Teuravuoman epätasaiseen kasvuun johtavista tekijöistä. Suo 7(1): 3—7.
— 1973. Kasvuturve ja sen käyttö. Helsinki.
RAITIO, H. & RANTALA, E. M. 1977. Männyn kasvuhäiriön makro- ja mikroskooppisia oireita. Oireiden kuvaus ja tulkinta. Summary: Macroscopic and microscopic symptoms of a growth disturbance in Scots pine. Description and interpretation. Commun. Inst. For. Fenn. 81(1): 1—29.
RAJARATNAM, J. A. & LOWRY, J. B. 1974. The role of boron in the oilpalm (*Elaeis guineensis*). Ann. Bot. 38: 193—200.
ROBERTSON, G. A. & LOUGHMAN, B. C. 1974. Reversible effects of boron on the absorption and incorporation of phosphate in Vicia faba. New Phytol. 73: 291—298.
SAGISAKA, S. 1972. Decrease of glucose 6-phosphate and 6-phosphogluconate dehydrogenase activities in the xylem of Populus gelrica on budding. Plant physicol. 50: 750—755.
— 1974. Transition of metabolism in living poplar bark from growing to wintering stages and vice versa. Plant physiol. 54: 544—549.
SCHÜTTE, K. H. (Ed). 1959. Trace element problems in nature. Bot.dept. Univ. Capetown.
SHKOLNIK, M. J. 1974. General conception of the physiological role of boron in plants. Sov. Plant physiol. 21(1): 174—186.
— , MAJEVSKAYA, A. N. & SOLOVJOVA, E. A. 1961. The significance of boron in the nucleate metabolism. Ref. V. Intern. biochem. congr. 2: 468.
— & SOLOVJOVA, E. A. 1961. On the physiological role of boron in plants. Dobl. Akad. Naub. SSSR 77: 137—140. (cited after C.A:n 1951 45:abstr. 8089).
SILFVERBERG, K. 1979. Männyn kasvuhäiriön ajoittuminen ja alkukehitys turvemaan boorin puutosalueella. Abstract: Phenology and initial development of a growth disorder in Scots pine on boron deficient peatland. Folia For. 396: 1—19.
SILLANPÄÄ, M. 1975. Hivenaineet suoprofiilissa. Distribution of trace elements in peat profiles. Suo 26(5): 83—86.
SMITH, P. F. 1962. Mineral analysis of the plant tissue. Ann. Rev. Pl. Phys. 13: 81—108.
STOATE, T. N. 1950. Nutrition of the pine. Forestry and Timber Bureau (Aust.) Bull. 30: 1—56.
TIMASHOV, N. D. 1966. Tez. dobl. 3 nautshn bong. po nubleinovym kislotam u restenij. ufa (cited by Shkolnik 1974).
TOLONEN, K. 1974. Suomen keidassuovesien ravinteista. Summary: On the nutrient content on the surface water in ombrotrophic mire complexes in Finland. Suo 25(3—4): 45—51.
TORSSELL, K. 1956. Chemistry of arylboric acids. IV. Effects of arylboric acids on wheat roots and the role of boron in plants. Physiol Plant. 9: 652—664.
VEIJALAINEN, H. 1975. Kasvuhäiriöistä ja niiden syistä metsäojitetuilla alueilla. Summary: Dieback and fertilization on drained peatlands. Suo 26(5): 87—92.
— 1977. Use of needle analysis for diagnosing micronutrient deficiencies of Scots pine on drained peatlands. Commun. Inst. For. Fenn. 92(4): 1—32.
— 1978. Metsäpuiden latvakadon esiintymisestä Suomessa. Summary: Occurence of dieback of forest trees in Finland. Metsäntutkimuslaitoksen suontutkimusosaston tiedonantoja 1/1978. Helsinki.
— 1980. Eräiden hivenlannoitteiden käyttökelpoisuus suometsien lannoituksessa. Neulasanalyysiin perustuva tarkastelu. Summary: Usability of some micronutrient fertilizers in peatland forests. Report basing on needle analysis. Folia For. 443: 1—15.
WALKER, J.R.L. 1973. Positive feedback mechanism and plant disease. Mauri Ora 1: 137—140.
WATANABE, R., CHORNEY, W., SKOK, J. & WENDER, S. H. 1964. Effect of boron deficiency on polyphenol production in sunflower. Phytochem. 3: 391—393.

Total of 63 references

ELECTRIC POINT DISCHARGES AND ATMOSPHERIC NITROGEN DIOXIDE IN CONIFEROUS FORESTS

Asko M. Aurela and Risto Punkkinen

The object of the present study is the alleged significance of natural electric point discharges (corona discharges) and of natural atmospheric NO_2 for coniferous forests. Field experiments were carried out in the summers of 1981 and 1982 on four rural sites in Finland in latitudes 61°—70° N. The average concentration of NO_2 in air was found to be 2 ± 1 $\mu g/m^3$. During the corona currents, the concentration increased by about 100 %. The duration of coronas amounted to about 2 % of time. No data are yet available about the rates of absorption and adsorption of NO_2 by plants in Finland. However, the coniferous trees and several forest-floor plants have been found to be sensitive to NO_2 pollution. Therefore, reference was made to the measurements of these rates carried out elsewhere by using plants which have been classified as sensitive to NO_2. On the basis of these data, the uptake of atmospheric NO_2 nitrogen by the plants of a spruce forest in Kuusamo (66°N, 29°E) was estimated to be of the order of magnitude of 1 kg(N)/ha during one growing season. This amount should be high enough to drive the evolution of plants in favour of this kind of N uptake.

The adsorption of NO_2 onto pine needles (0.7 g(N) day^{-1} ha^{-1}) could explain an observation about leaching, according to which the content of N in throughfall in a pine stand (61°N, 24°E) is higher than in free rain fall. The estimated effect of the increase of NO_2 during corona currents on the yield of seeds by spruces may just reach the theoretical minimum advantage which might drive the evolution. However, the advantage could have been larger in mountains, where many spruce species are believed to have developed. The hypothetical link between the natural corona currents and the N assimilation was also used in a proposed process model of growth disturbances of northern trees.

Introduction

In 1873—1904, a Finnish researcher of atmospheric physics, Professor K. S. Lemström (1904), proposed and studied many hypotheses concerning botany. Among others, the following interrelated hypotheses were propounded by him: 1) Atmospheric electricity produces point discharges or coronas at the tips of plants, and plants utilize this phenomenon in various ways. 2) Atmospheric nitrogen dioxide, which is produced by coronas in addition to many other production mechanisms, is absorbed by the stomata of plants and used as a nutrient. 3) These phenomena are significant for plants particularly in cool climates. 4) The same phenomena have been influential in the evolution of plants, for example, of coniferous needles. 5) In unfavourable conditions plants are damaged by strong atmospheric electric fields.

The main reasons for undertaking a study of the listed hypotheses were the following: i) Some useful experiments concerning these hypotheses could be carried out by means of common laboratory equipment, without specially allocated funds. ii) The same experiments were urgent from the point of view of meteorology and environmental study, irrespective of the botanical hypotheses. Indeed, the field measurements of the corona currents and of the concentration of the atmospheric NO_2 supplemented similar researches carried out at the Finnish Meteorological Office. iii) A search of the botanical literature and discussions with experienced botanists brought up some alleged problems

or discrepancies which could conceivably be explained by the listed hypotheses. Semiquantitave trials of such explanations are reported in the following sections. iv) Some other recent experiments, which are different from the present ones, also lend support to the hypotheses, as mentioned in Discussion (cf. Yoneyama et al. 1980). v) A previous study, which concerned mainly lichens (Aurela and Punkkinen 1981), supported Lemström's hypotheses.

Significance of atmospheric nitrogen dioxide for northern coniferous forests

Concerning the hypothesis that NO_2 would be significant for coniferous forests particularly in cool climates, the nitrogen budget of a spruce forest in Kuusamo (66°N, 29°E) (Havas 1977 and 1979) seems to be the most appropriate test material available at present. Havas emphasized that the forest suffers, above all, from a deficiency of nitrogen. Unfortunately, the rates of uptake of NO_2 have not been measured for the plants in question, viz. the Norway spruce (*Picea abies*), dwarf shrubs, and mosses. In order to obtain preliminary estimates of the significance of NO_2, we have to use some rates of uptake measured for other plant species in other countries.

Bengtson et al. (1982) reported the deposition velocities of NO_2 for the needles of Scots pine (*Pinus sylvestris*) in summer conditions at Jädraås in Sweden (61°N, 16°E). The Scots pine is a comparatively satisfactory reference species for the present work, because it belongs to conifers and is sensitive to NO_2. The deposition velocities, v_n, were 0.65—1.67 mm/s for daytime and 0.28—0.78 mm/s for night time. Noting the light summer in Kuusamo, we use the value $v_n = 1$ mm/s for spruce needles in our preliminary calculation.

When starting from the quantity v_n, the mass of the NO_2 absorbed by the needles is obtained from the formula

$$m = v_n A_n c t.$$

Here, A_n is the total area of the needles within a unit area of ground, c is the concentration of NO_2 in air, and t is time.

According to Havas (private communication in 1982), A_n is 7.2 m^2/m^2 (ground). We use for c the average value 2 $\mu g/m^3$, which refers to rural areas in Finland (Punkkinen and Aurela 1982). (In summer 1982, the value of c was also measured in Kuusamo at the Oulanka Biological Station, which is close to the spruce stand considered. The result was 2.6 $\mu g/m^3$, but it may contain anthropogenic NO_2 due to combustion and motor vehicles.) The time t is taken to be the duration of the conventional growing season (mean temperature above 5°C). In Kuusamo, t is 140 days (Laaksonen 1979).

On the basis of the quoted data, we obtain $m = 0.17$ g/m^2. This would mean 0.5 kg available nitrogen per hectare. The amount of N needed for the annual growth of the above-ground biomass of the spruces is about 20 kg/ha (Havas 1979). Thus, the absorbed NO_2 would contribute about 3 % of that. Assuming that N is the critical element in the production of seeds, this would mean roughly a 3 % relative advantage in the production of offspring. Theoretically, such an advantage could explain the evolution of the quality which generates the advantage (Li 1963, p. 257), viz. the ability of utilizing NO_2.

A similar relative contribution of NO_2 nitrogen could be found for the forest-floor vegetation, if the Scots pine would be assumed to be representative of the NO_2 uptake of the forest-floor plants. However, there would be equally good reasons to use other reference species, and in fact, that would be important for the sake of comparison.

Matsumaru et al. (1979) have measured the rate of absorption of NO_2 per unit of biomass for several species.

From among the alternatives, we choose the sunflower and the tomato as the reference species, because these two have previously been classified as sensitive to NO_2 (Bond and Staub 1979).

In terms of the quantities used by Matsumaru et al. (1979), the formula of m is written in the form

$$m = KM\varrho t,$$

where K is the rate of absorption of NO_2, M is the biomass of the absorbing plant, and ϱ is the volume fraction of NO_2 in air. The

mean value of K for the above-ground parts of the sunflower and tomato is 0.0092 ppm^{-1} day^{-1}. According to Havas (1979), M is 0.56 kg/m^2. The value accepted for c correspond to $\varrho = 0.001$ ppm. These data give the estimate $m = 0.72$ g/m^2, which means about 2 kg available N per hectare.

The value of m is larger than that obtained in the case of the needles mainly because K is larger. The value of v_n would correspond to the value $K = 0.002$ ppm^{-1} day^{-1}, assuming that $M_n = 0.4$ kg/m^2 (Bringmark 1977) and $A_n = 5$ m^2 per m^2 of ground (Bengtson et al. 1980).

The result is next compared with the amount of N needed for the annual growth of the above-ground biomass of the forest-floor vegetation, 15 kg/ha (Havas 1979). According to the present estimates, the evolutionary effect should be pronounced, and the NO_2 nitrogen might even be significant in the nitrogen budget measured by Havas (1979).

Adsorption and leaching of nitrogen dioxide

It has been commonly accepted that rain fall does not leach nitrogen compounds down from a forest canopy (Mälkönen 1974, Päivänen 1974, Khanna 1981). Therefore the finding of Lehtonen (1977) that in a Scots pine stand in southern Finland (61°N, 24°E) the nitrogen content of the throughfall was higher than that of the free rain fall presented a kind of problem. On the average, the extra amount of N was 0.3 g $day^{-1}ha^{-1}$. This is negligible in the N budget of the forest, but to explain its origin, we study the hypothesis that this amount would be due to adsorbed NO_2 which is washed down by rain from the surface of the needles and twigs.

The area of the relevant surface is not known accurately, but in this application an estimate of the order of magnitude is adequate. On the basis of the known characteristics of the stand, we estimate that the area is about 7 m^2/m^2 (ground).

According to Elkiey and Ormrod (1981), the rate of adsorption of NO_2 to the leaf surfaces of nine different cultivars of turfgrass (*Poa pratensis*), exposed continuously to 0.5 ppm of NO_2, is approximately 0.1 μl $min^{-1}dm^{-2}$ (one-sided leaf area), with a range of about ± 50 %. This would mean about 8 mg(N) $day^{-1}ppm^{-1}m^{-2}$ (total leaf area). The rate of adsorption could be assumed to be approximately the same for the needles of Scots pine, because both plants have cuticle.

By using the average concentration of NO_2 observed in southern Finland, 0.0013 ppm (Punkkinen and Aurela 1982), we find the estimate of the adsorption rate, 0.7 g(N) $day^{-1}ha^{-1}$. This amount could explain the leached nitrogen observed by Lehtonen (1977).

The process model can be elaborated by taking into account the saturation of the adsorbing surface during long periods of fair weather and the absorption of water directly into the needles, particularly during slight rains. The calculated amount of leached nitrogen would then become smaller.

Increase of atmospheric nitrogen dioxide by natural point discharges

The yield of NO_2 by natural point discharges was preliminarily observed in 1978 through 1980 in the ambient air in various conditions (Aurela and Punkkinen 1981). In the following summers, three new cases were observed in the city of Turku (60°N, 22°E) by means of improved equipment. In June and August 1981, three cases were observed on rural sites in Luumäki and Savitaipale (61°N, 28°E). In both urban and rural conditions, the average relative increases of c were roughly the same, 1.12 ± 0.17 and 1.20 ± 0.22, respectively (statistical errors given). An increase was observed in c every time when the duration of the corona currents was long enough (about 10 min) to produce an increase distinct from other variation. The response of the detector was deteriorated by the adsorption of the extra NO_2 on the walls of the plastic tubes of the air intake. Many trials, carried out by increasing c artifically, showed that the measured increases could be too small by several tens per cent, but no correction has been applied to the results above.

Concerning the total duration of the corona currents, the previous report (Punkkinen and Aurela 1982) can be updated as follows. During a total measuring time of 576 hours, the duration of corona currents in copper electrodes in rural areas in Finland was 1.9 % of time. Thus, the integrated relative increase of c would be $0.019 \times 1.2 \approx 0.02$. The corresponding advantage in the production of seeds, considered in section 2, would be $0.02 \times 3\ \% = 0.06\ \%$. If the smallest advantage capable of driving the evolution in a constant environment is 0.1 % (Li 1963, p. 257), the effect of the NO_2 production by coronas may just reach this theoretical limit.

Of course, the environment has not remained constant, nor has the relevant NO_2 production remained proper.

So far our measurements have concerned lowlands in Finland. However, attention should be drawn to the origin of spruces (e.g. Schmidt-Vogt 1977). Many of the spruce species are believed to have originated in certain mountainous regions of present China. In mountains, the corona discharges are promoted by the intensification of electric fields and by the decrease of the air pressure. Lemström (1885) already reported observations of large-scale corona discharges around mountain tops (reviewed by Silverman and Tuan 1973, p. 193). Reiter (1970) has observed at the Wank mountain station during thunderstorms peak values of c around $5 \mu g/m^3$ and up to $80\ \mu g/m^3$, while the background level was lower than in Finland at present. Moreover, the global circulation of atmospheric electricity may have been stronger during the periods of high cosmic-ray intensity in the last 10^6 years (Markson 1981, Hughes 1982).

It is still possible that Lemström (1904, p. 3) was right in claiming that the purpose of the needle-shaped leaves is "to be the means through which the electricity goes from the atmosphere into the earth, or vice versa".

This is not to say that the NO_2 production would be the most significant advantage gained by plants from the natural corona currents (cf. Zhurbitsky 1972).

Discussion

Because of the importance of nitrogen to plants, the NO_2 uptake could also be expected to have a bearing on other problems. Indeed, Grubb (1977) has asked, with reference to rain-forest trees: "What is the advantage to taller plants in having higher stomatal densities?" The explanation may be in the corona discharges occurring at the tops of the trees under electric clouds, which are just typical in the areas of rain forests. The discharges would produce NO_2, which would then be available just in the vicinity of the stomata.

As mentioned in the introduction, plants are supposed to utilize natural electric currents in many different ways. According to recent experiments, the passage of weak electric currents through plants promotes the uptake of mineral nutrients (Zhurbitsky 1972) and redistributes auxin (Morris 1980). An observation of electrotropism in spruce shoots (Aurela 1981) can probably be explained by such a redistribution effect.

If the plants have adapted to the normal strengths of the corona currents, an abnormally strong current would of course do damage. A hypothetical link between the nitrogen assimilation and the corona currents may even have a bearing on growth disturbances. Huikari (1977) has concluded that the micro-nutrient deficiencies of soil correlate with growth disturbances in trees. Such deficiencies might also be caused by corona currents through the enhanced uptake of mineral nutrients (Zhurbitsky 1972), but they are not considered further in this context. Here we suggest a process model for the damage, including several phases. A strong corona current is assumed to occur in the autumn, as a kind of meteorological rarity. This current increases protein synthesis (Black et. al. 1971), which means an interruption of the hardening process (e.g. Havas 1977). Because of the delay of the hardening, the tops of a few young trees are damaged during a subsequent frost. The damage is observed the following spring. Such a process is not of course thought to be the only possible cause of growth disturbances. However, this process might explain, for example, the frost damage reported by Yli-Vakkuri (1971).

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Literature

AURELA, A. 1981. Havupuiden elektrotropismi. Summary: Electrotropism in fir trees. Luonnon Tutkija 85(5): 211—212.

— & PUNKKINEN, R. 1981. Atmospheric nitrogen dioxide and northern plants. Rep. Kevo Subarctic Res. Stat. 17: 1—6.

BENGTSON, C., BOSTRÖM, C-Å, GRENNFELT, P., SKÄRBY, L. & TROENG, E. 1980. Deposition of nitrogen oxides to Scots pine (Pinus sylvestris L.). Proc. Int. conf. ecol. impact acid precip., Norway 1980, SNSF-project, p. 154—155.

— , GRENNFELT, P., BOSTRÖM, C-Å., TROENG, E., SKÄRBY, L., SJÖDIN, Å. & PETERSON, K. 1982. Deposition and uptake of nitrogen oxides in Scots pine needles (Pinus sylvestris L.). Report B 647, Swedish Water and Air Pollution Research Institute, Gothenburg.

BLACK, J. D., FORSYTH, F. R., FENSOM, D. S. & ROSS, R. B. 1971. Electrical stimulation and its effect on growth and ion accumulation in tomato plants. Canad. J. Bot. 49(10): 1809—1815.

BOND, R. G. & STRAUB, C. P. S. 1979. Handbook of Environmental Control. Vol. I: Air Pollution. 3rd print. CRC Press, Boca Raton, Florida. 576 pp.

BRINGMARK, L. 1977. A bioelement budget of an old Scots pine forest in Central Sweden. Silva Fennica 11(3): 201—257.

ELKIEY, T. & ORMROD, D. P. 1981. Sorption of O_3, SO_2, NO_2 or their mixture by nine Poa pratensis cultivars of differing pollutant sensitivity. Atmospheric Environment 15(9): 1739—1743.

GRUBB, P. J. 1977. Leaf structure and function. In: (Eds. Duncan, R. & Weston-Smith, M.). The Encyclopaedia of Ignorance. Vol. 2. Life Sciences. Pergamon Press, Oxford. pp. 317—329.

HAVAS, P. 1977. Lapin kuusikot — esimerkki metsän ekologisista ulottuvuuksista. Summary: The spruce forests of Lapland — an example of the dimensions of forest ecology. In: (Ed. Vuorela, L.A.). Academia Scientiarum Fennica Year Book 1977. Helsinki. pp. 143—153.

— 1979. Paksusammaltyypin kuusimetsän typpitaloudesta. Summary: The nitrogen economy of a Hylocomium-Myrtillusstet type spruce forest. Acta Univ. Oul., Ser. A No. 68, Biol. No. 4: 135—140.

HUGHES, D. W. 1982. Meteorite erosion and cosmic ray variations. Nature 295(5847): 279—280.

HUIKARI, O. 1977. Micro-nutrient deficiencies cause growth-disturbances in trees. Silva Fenn. 11(3): 251—254.

KHANNA, P. K. 1981. Leaching of nitrogen from terrestrial ecosystems — patterns, mechanisms and ecosystem responses. Ecol. Bull. 33: 343—352.

LAAKSONEN, K. 1979. Effective temperature sums and durations of the vegetative period in Fennoscandia (1921—1950). Fennia 157(2): 171—197.

LEHTONEN, I. 1977. Ravinteiden kierto eräässä männikössä: III Maaperän, kasvillisuuden ja sadeveden ravinnepitoisuuksien vaihtelu. Summary: Nutrient cycle in a pine stand: III Variation in nutrient content of soil, vegetation, and precipitation. Silva Fenn. 11(3): 184—194.

LEMSTRÖM, S. 1885. The results of the scientific expedition to Sodankylä. Nature 31(799): 372—376.

LEMSTRÖM, S. 1904. Electricity in Agriculture and Horticulture. The Electrician Pub. Co., London. 72 pp.

LI, C. C. 1963. Population Genetics. 4th impr. Univ. Chicago.

MARKSON, R. 1981. Modulation of the Earth's electric field by cosmic radiation. Nature 291(5813): 304—308.

MATSUMARU, T., YONEYAMA, T., TOTSUKA, T. & SHIRATORI, K. 1979. Absorption of atmospheric nitrogen dioxide by plants and soils. I. Quantitative estimation of absorbed nitrogen dioxide in plants by nitrogen-15 method. Soil. Sci. Plant Nutr. 25(2): 255—265.

MORRIS, D. A. 1980. The influence of small direct electric currents on the transport of auxin in intact plants. Planta 150(5): 431—434.

MÄLKÖNEN, E. 1975. Annual primary production and nutrient cycle in some Scots pine stands. Commun. Inst. For. Fenn. 84(5): 1—87.

PÄIVÄNEN, J. 1974. Nutrient removal from Scots pine canopy on drained peatland by rain. Acta For. Fenn. 139: 1—19.

PUNKKINEN, R. & AURELA, A. M. 1982. Environmental study of atmospheric NO_2 in Finland. Proc. XVI Ann. Conf. Finnish Phys. Soc. (Eds. T. Katila & O. Parviainen). Report TKK-F-A 466, paper 8: 15. Techn. Univ. Helsinki.

PUNKKINEN, R. & AURELA, A. M. 1982. Occurrence of air-earth corona discharges in south Finland. Proc. XVI Ann. Conf. Finnish Phys. Soc. Report TKK-F-A 466, paper 9:2. (see above)

REITER, R. 1970. On the causal relation between nitrogen-oxygen compounds in the troposphere and atmospheric electricity. Tellus 22: 122—136.

SCHMIDT-VOGT, H. 1977. Die Fichte. Band I. Paul Parey, Hamburg.

SILVERMAN, S. M. & TUAN, T. F. 1973. Auroral audibility. Adv. in Geophysics 16: 155—266.

YLI-VAKKURI, P. 1971. Havaintoja latvakasvainten pakkasvaurioista kuusen taimistoissa Itä-Savossa. Summary: On winter frost damages to the leaders of Spruce saplings in eastern South-Finland. Silva Fenn. 5(2): 96—104.

YONEYAMA, T., HASHIMOTO, A. & TOTSUKA, T. 1980. Absorption of atmospheric nitrogen dioxide by plants and soils. IV. Two routes of nitrogen uptake by plants from atmospheric NO_2: direct incorporation into aerial plant-parts and uptake by roots after absorption into the soil. Soil Sci. Plant Nutr. 26(1): 1—7.

ZHURBITSKY, Z. I. 1972. Atmospheric electricity and plant nutrition problems. Soviet Soil Sci. 1972 (2): 176—187.

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SESSION 5.

PREVENTION AND CURE OF GROWTH DISTURBANCES IN FOREST TREES

PRELIMINARY RESULTS OF MICRONUTRIENT FERTILIZATION EXPERIMENTS IN DISORDERED SCOTS PINE STANDS

Heikki Veijalainen

Part of the micronutrient fertilization experiments established in disordered Scots pine areas in Finland since 1959 had been inventoried by 1982. Fertilizer borate, wood ash and various micronutrient mixtures containing boron have given some promising results in controlling the growth disorder. Copper has given positive results in certain areas. On the other hand, manganese sulphate or zinc sulphate alone have not helped to control the disorder. About 1 kg/ha of elemental boron and about 6 kg/ha of elemental copper are required to achieve good results in pine stands growing on drained peatlands.

Micronutrient fertilization was not found to have any positive effects if the growth disturbance had reached the chronic dieback stage before the experiment had been established, or if the macronutrient status of the site was out of balance.

Introduction

A number of different micronutrient fertilizer treatments have been used in experiments into the control of growth disturbances in Finland ever since Prof. Olavi Huikari (1974, 1977) published his hypothesis about the effect of micronutrient deficiencies on the development of growth disturbances. This hypothesis was partly based on information obtained from abroad (e.g. Benzian 1957, 1965, Haveraaen 1964, 1966, Lange 1969, Ludbrook 1940, Rademacher 1940, Shorrocks 1974, Smith 1943, Stoate 1950, Stone and Will 1965, Stone 1968, Vail et al. 1961, Will 1971, 1972), and partly on information about micronutrient deficiencies in gardens and cultivated land in

Finland (e.g. Tainio 1953, Jamalainen 1968, Kurki 1972). In addition to this, the results of experimental activity carried out at the time on drained peatlands indicated that there was a need for micronutrients when intensive forestry is practised (Reinikainen 1968, Paarlahti et al. 1971, Veijalainen 1977). Furthermore, a number of the micronutrient fertilizer experiments established in the 1950's by Huikari were situated quite by chance in the immediate vicinity of growth disturbance areas. The fact that the experiments developed without showing any signs of growth disturbances, immediately brought up the question of micronutrients, just in the same way as the excellent growth results obtained with wood ash since the 1930's.

The results of some of the individual experiments are examined in the following and an attempt is made to give a preliminary picture of the micronutrient fertilizers suitable for use in the control of the growth disturbances.

Material and methods

All the experiments have been established in pine-dominated small-sized (2—5 m) stands growing on drained and fertilized peatlands (Table 1). In the Kivisuo II experiment, however, seedlings (2+0) which had just been planted were fertilized.

Most of the sites have previously been open swamps. Volume results are available for the Kivisuo II experiment only. In the other experiments, the results for height growth after micronutrient fertilization and changes in the nature or frequency of the growth disturbances, have to suffice. The sample plots in some of the experiments have already been refertilized (Kivisuo 1975 and Suomussalmi). The micronutrient fertilizers have been spread on top of the soil in all of the experiments dealt with here.

Results

Kivisuo II

Kivisuo II was measured 20 years after the experiment had been established (see Veijalainen 1981). Fertilizer borate (50 kg/ha) increased the following parameters to a significant degree:

1) mean stem size
2) total height of the pines and
3) reduced the incidence of the growth disturbance (Table 2).

Copper sulphate (50 kg/ha) increased, to a significant degree, the combined volume of stems with a volume of over 100 litres and reduced the incidence of the growth disturbances.

Manganese sulphate (50 kg/ha) reduced the number of growth disturbances. Zinc sulphate (50 kg/ha) was not found to have any statistically significant effect (Table 2). Owing to the great heterogeneity of the stem number of the sample plots, none of the micronutrients used had increased the total volume or volume growth of the stand (1974—1978), nor the basal area.

The experiment demonstrated that micronutrient fertilization carried out at an early

Table 1. Details of the micronutrient fertilization experiments at the time of establishment.

Name and location of experiment	Year of establishment	Year measured	Site data: Original peatland type 1)	Site data: Ditch spacing m	Experimental design	Micronutrients, kg/ha
Kivisuo II, 61°53′N	1959	1978	HPD	11	2×2^4	B7, Cu12, Mn13, Zn11
Kivisuo, 1975 "	1975	1978	HPD	11	9×2^3	B1,4, Cu2,5, Mn13
Valtimo, 63°48′N	1979	1981	RiTSN	20	2×2^4	B2,8, Cu7,8, Mn5,2, Zn4,6
Ähtäri, 62°30′N	1979	1981	PsN	30	2×2^4	B2,8, Cu7,8, Mn5,2, Zn4,6
Pyhäntä, 64°01′N	1978	1981	AAP	10	2×6 levels	wood ash 1000—20000
Pyhäjoki, 64°25′N	1974	1981	RhR	30—60	3×4 treatments	B1,1 and two commercial micronutrient mixtures
Kuhmo, 64°10′N	1975	1981	SR	20—60	3×4 "	
Suomussalmi, 64°50′N	1975	1981	SR	30	2×3 "	B1,4 + Cu2,5 + Mn7,8

1) Sites: HPD = Hydro-peat drying field (Sphagnum fuscum-rich cottongrass mire)
RiTSN = Cottongrass-rich sedge mire with rimpis
PsN = Carex globularis mire
AAP = Abandoned agricultural field on peatland
RhR = Herb-rich pine swamp
SR = Sedge pine swamp

Table 2. Factorial mean effects, Kivisuo exp. II.

Factor	Volume of the stand m^3/ha	dm^3/stem	Saw timber m^3/ha[1)]	Growth 1974—78 m^3/ha	Number of stems per hectare	Height cm	$D_{1,3}$ cm
(Cu)	0,3	1,9	2,4*	—0.3	—95	13	0,2
(B)	—4,2	4,9*	0,7	—2,9	—290	22*	0,3
(Cu B)	—5,1	—4,7*	—2,4*	—1,0	86	—16	—0,7*
(Mn)	2,5	—1,0	—1,8	0,2	84	—0	—0,5
(Cu Mn)	8,0	2,9	—2,7*	2,9	248	—11	—0,8*
(B Mn)	—3,3	0,5	1,4	—0,1	—51	0	0,2
(Cu B Mn)	4,3	—0,2	0,6	0,1	84	13	—0,3
(Zn)	5,6	—2,0	—0,7	3,0	180	—2	—0,7
(Cu Zn)	2,2	1,3	—0,6	0,0	5	1	0,2
(B Zn)	4,1	—1,1	0,7	0,9	105	6	—0,2
(Cu B Zn)	10,7*	—1,6	0,8	5,3*	269	5	—0,5
(Mn Zn)	0,4	—0,5	1,8	—1,0	55	—3	—0,2
(Cu Mn Zn)	—1,3	0,6	—0,3	0,1	—60	—0	—0,1
(B Mn Zn)	—14,2*	3,2	2,0	—5,1*	—432*	—13	0,5
(Cu B Mn Zn)	—4,6	0,4	—0,1	3,5	—72	—10	0,4
Mean	71,2	45,0	2,8	34,5	1630	725	12,3

* = significant at 0,05 risk level
1) = stems with volume > 100 dm^3

stage can be used to prevent the development of serious growth disturbances, and further, that the cause of the growth disturbance is a deficiency of boron in this area. The results also indicated that there may be copper deficiency in certain parts of the area.

Kivisuo 1975

The basic treatments in this experiment were NPK fertilization in 1959 and PK-refertilization (500 kg/ha) in 1968. Sixteen -year-old pines which were showing clear signs of growth disturbances and which were supposed to be capable of recovering, were selected as sample trees. The micronutrient fertilizers were spread over an area of 4 m^2 around each tree.

Treatments:
$MnSO_4$ 20 g/tree
$CuSO_4$ 4 g/tree
Fertilizer borate 4 g/tree

The mean height of the fertilized pines on the different sample plots (replications) in 1974 was 3,4—4,1 m, and the number of trees affected by the growth disturbance varied from 42—90 %. The growth disturbance had already reached the chronic stage in many plots. There was also some snow damage.

By 1978, 26,4 % of the sample trees had died and it was apparent that this trend would continue. 60,4 % of the surviving trees showed clear signs of recovery. Recovery was most apparent in the group of control trees. Both boron and manganese had reduced the rate of recovery to a statistically significant degree (Veijalainen 1979).

In this case the growth disturbance had probably proceeded too far before the micronutrient fertilization was carried out. Another phenomenon was the spontaneous recovery of trees affected by the growth disturbance. This affects the interpretation of the results of many of the micronutrient fertilization experiments. It has been suggested that this is due to annual variations in the climatic conditions and the gradual enlargement of the root systems. In this case, the effect of heavy refertilization has definitely started to fall off very rapidly, perhaps as a result of the wet summer in 1974. Refertilization carried out too soon after the basic fertilization at Kivisuo has been shown to be one reason for the growth disturbance (Veijalainen 1975).

Valtimo

The experimental design used in the Valtimo experiment is the same as that for

the Kivisuo II experiment, i.e. a 2^4 factorial design. The following amounts of micronutrient fertilizers were applied in 1979:

Fertilizer borate	(14 %) 20 kg/ha
Copper oxide	(78 %) 10 kg/ha
Zinc sulphate	(23 %) 20 kg/ha
Manganese sulphate	(26 %) 20 kg/ha

Top die-back and the initial signs of the growth disturbances were commonly present among groups of apparently healthy trees when the Valtimo experiment was established.

The differences in the height growth in growth disturbance classes had not evened out in 1980 ($F = 77{,}98^{***}$). This indicates that recovery from the growth disturbance does not occur as rapidly under Finnish conditions as it does in warmer climates (cf. Vail et al. 1961, Will 1972). However, in 1980 boron had clearly already increased the height growth of healthy looking trees and those only slightly affected by the growth disturbance. The height growth of the trees most seriously affected by the growth disturbance had been increased by the addition of copper. In this experiment, too, recovery was clearly strongest on the control plots.

Ähtäri

The experimental design and the treatments were the same as those used in the Valtimo experiment. The micronutrient treatments were not even able to halt the increase in the growth disturbance in the group of healthy trees. This is a rather worrying feature. While 35,4 % of the healthy trees in the whole experiment developed the growth disturbance during the period 1979—81, only 27,6 % of the affected trees recovered. On the other hand, the trees affected by die-back were starting to recover. Altogether 76,4 % of such trees were later classified as slightly affected or completely healthy (0,7 %).

The effects of the micronutrient fertilizers were statistically significant in the group of healthy trees only. Boron increased and copper decreased height growth in this group in 1980.

The effect of boron was still statistically significant after the Valtimo and Ähtäri materials were combined. The F-value of the fertilizer treatments was $2{,}47^{**}$, which shows that the micronutrient fertilizers had in fact already had an overall effect on the height growth of these two pine stands.

Pyhäntä

Poor-quality wood ash cured almost all the growth disturbance symptoms in the growth disturbance area as well as fungal infections on the pines, within three growing periods. The difference between the total height of the healthy trees and that in the different growth disturbance classes (light, severe) were still present four years after fertilization ($F = 73{,}81^{***}$).

Only the largest amount of wood ash (20 000 kg/ha) increased the height growth (1978—81) of the healthy trees to a statistically significant extent. Wood ash, already at a level of 5000 kg/ha, significantly increased height growth in the class of trees with slight growth disturbances. The growth increases were quite small in the case of trees severely affected by the growth disturbance. The wood ash levels of more than 5000 kg/ha gave statistically significant differences when all the tree groups were included. The growth reaction produced by wood ash during the first two years after fertilization was apparent as luxurious development of the needles. The increase in height growth clearly began during the third summer.

Pyhäjoki and Kuhmo

These single-tree experiments are among the oldest of the micronutrient fertilization experiments established in growth disturbance areas. Both boron and a micronutrient mixture brought about a recovery in height growth at Pyhäjoki of over 45 cm/yr (1977—81). This is a good result. At Kuhmo, only fertilizer borate gave a result better that the control. When the materials are combined, the clearest growth-improving result is given by fertilizer borate (see Table 3).

Needle samples were taken from the experiment at Kuhmo for chemical analysis in autumn 1981. The control trees were not suffering from any nutrient deficiencies

Table 3. Mean height growth of the pines in the Pyhäjoki and Kuhmo experiments, cm/yr.

Micronutrient fertilizer	Pyhäjoki		Kuhmo	Mean
	1977—81	1974—81	1974—81	1974—81
Control = PK	23,9	25,0	28,1	26,6
PK + Cu + B	32,7	22,1	28,6	25,4
PK + micronutrient mixture	46,7	32,5	22,3	27,4
PK + fertilizer borate	55,3	38,7	34,3	36,5

apart from an evident deficiency of boron. The results for the boron content of the needles were as follows:

	B, ppm
Control = PK	4,3
PK + Cu + B	8,9
PK + micronutrient mixture (cont. B)	10,0
PK + fertilizer borate	13,2

Fertilizer borate, as well as the micronutrient mixtures, were found to have increased the boron content of the needles to a level above the deficiency limit (B = 7,0 — 10,0 ppm) presented by Kolari (1979).

Suomussalmi

The experimental area started to suffer from growth disturbances after basic NPK-fertilization had been carried out in 1962—63. When the experiment was refertilized in 1975 with NPK, fertilizer borate (10 kg/ha), copper sulphate (10 kg/ha) and manganese sulphate (30 kg/ha) were also added.

The mean height growth for the period 1975—80 was as follows:

Refertilization	cm/yr.
0	22,0
NPK	23,2
NPK + CuBMn	29,4

NPK refertilization alone has had a very weak effect on height growth. The effect of the self-made micronutrient mixture was quite strong. This result is primarily caused by the almost complete recovery of trees badly affected by the growth disturbance (27 % of the badly affected trees) on the micronutrient sample plots, as well as by the appearance of new cases of growth disturbed trees on the sample plots refertilized with NPK only (58,3 % of the originally healthy trees). Moreover, the number of mild growth disturbances had increased on the control and NPK sample plots and decreased on the NPK + CuBMn plots owing to micronutrient treatment.

Discussion

The micronutrient fertilizers used in the experiments described here contained 1,1—7,0 kg/ha of boron and 2,5—12 kg/ha of copper. No toxicity symptoms were found, even with the largest doses. The relative ineffectiveness of copper may to some extent be due to the fact that, in part of the experiments, the amount of copper given was very small in comparison to the optimum level (6 kg Cu/ha) proposed by Veijalainen (1980).

The wood ash used in the Pyhäntä experiment was of very poor quality. It contained 18—50 mg/kg of copper and 38—102 mg/kg of boron. Thus the largest application of wood ash (20 000 kg/ha) contained only 0,4—1,0 kg/ha of copper and 0,8—2,0 kg/ha of boron. Presumably the amount of boron was sufficient, but that of copper too small.

The results for boron fertilization obtained in this study are similar to those presented by Braekke (1979), who also deals with Scots pine on peatlands — although on even less fertile sites in Norway.

It has earlier been shown that the growth of pines (e.g. *Pinus radiata)* can be improved on mineral soil sites by applying fertilizers containing boron (Stone and Will 1965). Haveraaen (1966) was able to cure boron deficiency symtoms *(Pinus sylvestris)* in pot experiments by means of borax fertilizer. Boron fertilizer almost completely cured a severe growth disorder on *Pinus radiata*

(Appleton and Slow 1966). Procter (1967) reported that boron fertilizer reduced in almost every case the incidence of growth disorders and improved growth in 26 boron experiments. On the other hand, die-back most probably caused by boron deficiency was not always cured by boron fertilization in pine forests in New Zealand (Will 1971). Vail et al. (1961) reported an experiment carried out using local pine species in which die-back symptoms were cured by spraying with a mixture of boron and zinc. Simultaneously die-back decreased outside the experimental area.

Rademacher (1940) did not obtain any marked results with $CuSO_4$ within two years in a heath area in northern Germany known to be deficient in copper. On the other hand, "copper deficiency symptoms" developed in his pot experiments *(Pinus sylvestris)* unless copper was added. Hall (1961) obtained a similar result with *P. radiata* in Australia. Another fertilizer experiment with *P. radiata* carried out in SE Australia exhibited clear "copper deficiency symptoms" (according to needle analysis a copper content of about 1,0 ppm). $CuSO_4$ did not completely cure the symptoms (Ruiter 1969). A growth disorder on sandy soil was cured with $CuSO_4$ fertilization, which raised the copper content of the needles from less than 1,0 ppm to about 3 ppm (Will et al. 1971). An especially interesting result was obtained in a *P. radiata* nursery in New Zealand. The substrate was peat. Treatment with copper resulted in healthy-looking seedlings in six weeks (Knight 1975).

The experiences gained abroad with both boron and copper are to a large extent similar to the results of our experiments. It is typical that the effect of boron fertilization can vary from excellent to a negative result, and the effect of copper fertilization is usually weak or incomplete.

Literature

APPLETON, E.J. & SLOW, L.J. 1966. Nutritional disorders and fertilizer trial in Pinus radiata stands in Waimea County, Nelson. N.Z.J. For. 11(2): 185—201.

BENZIAN, B. 1957. Copper deficiency in poplar. For. Comm. Rep. For. Res. 1957:98.

— 1965. Experiments on nutrition problems in forest nurseries. I. For. Comm. Bull. 37:1—251.

BRAEKKE, F.H. 1979. Boron deficiency in forest plantations on peatland in Norway. Medd. Nor. inst. skogsforsk. 35.3.

HALL, M.J. 1961. The establishment of pines on poor deep sands at Longford, Victoria. Appita 15(2): 68—76.

HAVERAAEN, O. 1964. Koppermangel hos gran. Summary: Copper deficiency on Norway spruce. Tidsskr. Skogbr. 72(3):289—300.

— 1966. Bor er også et noedvendig mikronaeringstoff for gran og furu. Norsk Skogbr. 22:788.

HUIKARI, O. 1974. Hivenaineet ja puiden kasvu. Metsä ja Puu 11/1974.

— 1977. Micronutrient deficiencies cause growth disturbances in trees. Silva Fenn. 11(3):251—254.

JAMALAINEN, E.A. 1968. Kasvien puutostaudit. 128 p. Kirjayhtymä. Helsinki.

KNIGHT, P.J. 1975. Copper deficiency in Pinus radiata in a peat soil nursery. N.Z.J. For. Sci. 5(2):209—218.

KOLARI, K.K. 1979. Hivenravinteiden puute metsäpuilla ja männyn kasvuhäiriöilmiö Suomessa. Kirjallisuuskatsaus. Abstract: Micro-nutrient deficiency in forest trees and dieback of scots pine in Finland. A Review. Folia For. 389:1—37.

KURKI, M. 1972. Suomen peltojen viljavuudesta II. Yhteiskirjapaino Oy. Helsinki, 182 s.

LANGE, T. 1969. A manganese deficiency in Pinus radiata at Klein Gouna, Knysna, For. S. Afr. 10:47—61.

LUDBROOK, W.V. 1940. Boron deficiency symptoms in pine seedlings in water culture. J. Comm. Sci. Ind. Res. (Aust.) 13:186—190.

PAARLAHTI, K., REINIKAINEN, A. & VEIJALAINEN, H. 1971. Nutritional diagnosis of Scots pine stands by needle and peat analysis. Seloste: Maa- ja neulasanalyysi turvemaiden männiköiden ravitsemustilan määrityksessä. Commun. Inst. For. Fenn. 74(5):1—58.

PROCTER, J. 1967. A nutritional disorder of pine. Commonwealth For. Rew. 46:145—154.

RADEMACHER, B. 1940. Kupfermangelerscheinungen bei Forstgewächsen auf Heideböden. Mitt. Forstwirtschaft und Forstwissenschaft. Heft 4:335—344.

REINIKAINEN, A. 1968. Ravinteiden puutosoireista puulajeilla. Teoksessa: Jamalainen, E.A. Kasvien puutostaudit. Helsinki, Kirjayhtymä. p. 101—109.

RUITER, J.H. 1969. Suspected Copper Deficiency in Radiata Pine. Plant and Soil XXXI (1): 197—200.

SHORROCKS, V.M. 1974. Boron deficiency — its prevention and cure. 55 p. London. Borax Consolidated Limited. Borax House.

SMITH, M.E. 1943. Micronutrients essential for the growth of Pinus radiata. Aust. For. 7:22—27.

STOATE, T.N. 1950. Nutrition of the pine. Forestry and Timber Bureau (Aust.) Bull. 30:1—56.

STONE, E.L. 1968. Microelement nutrition of forest trees: A review. In: Forest fertilization — theory and practice. Symp. For. Fert. April, 1967. Knowville, USA. Tennessee Valley Authority. Muscle Shoals, Ala., p. 132—175.

— & WILL, G.M. 1965. Boron deficiency in Pinus radiata and P. pinaster. For. Sci. 11(4):425—433.

TAINIO, A. 1953. Hivenaineiden puutteesta Suomen kasvinviljelyssä. Suom. kemistilehti 26:192—196.

VAIL, J.W., PARRY, M.S. & CALTON, W.E. 1961.

Boron deficiency dieback in pines. Plant and Soil 14(4):393—398.
VEIJALAINEN, H. 1975. Kasvuhäiriöistä ja niiden syistä metsäojitusalueella. Summary: Dieback and fertilization on drained peatlands. Suo 26(5):87—92.
— 1977. Use of needle analysis for diagnosing micronutrient deficiencies of Scots pine on drained peatlands. Seloste: Neulasanalyysi männyn mikroravinnetilanteen määrityksessä turvemailla. Commun. Inst. For. Fenn. 92:4:1—30.
— 1979. Hivenlannoitteiden Cu, B ja Mn vaikutus kasvuhäiriöpuuston elpymiseen Kivisuolla. Metsäntutkimuslaitoksen suontutkimusosaston tiedonantoja. 6/1979. 8 p.
— 1980. Eräiden hivenlannoitteiden käyttökelpoisuus suometsien lannoituksessa. Neulasanalyysiin perustuva tarkastelu. Summary: Usability of some micronutrient fertilizers in peatland forests. Report basing on needle analysis. Folia For. 443:1—15.
— 1981. Hivenlannoituksen vaikutus istutusmännikön kehitykseen turvemaalla. Summary: Long-term responses of Scots pine to micronutrient fertilization on acid peat soil. Folia For. 477:1—15.
WILL, G.M. 1971. The occurrence and treatment of boron deficiency in New Zealand Pine forests. Res. Leafl. For. Inst. N.Z. For. Serv. 32.
— 1972. Copper deficiency in Radiata pine planted on sands at Mangawhai Forest. N.Z.J. For Sci. 2(2): 217—221.
WILL, G.M., GADGIL, R.L. & KNIGHT, P.J. 1971. Copper deficiency in Mangawhai Forest. Rep. For. Res. Inst. 1970. N.Z. For. Serv. 30.

Total of 35 references

MICRONUTRIENTS — PROPHYLACTIC USE AND CURE OF FOREST GROWTH DISTURBANCES

Finn. H. Braekke

Major problems on afforested nutrient-poor peatland in Norway have been: radiation frost in the growing season on unlignified shoots of young *Picea abies*, freezing and/or drying out of improperly hardened apical shoots in autumn or winter — early spring periods, increased susceptibility to frost with age, "shoot dieback" in older plantations on both spruce and pines.

Critical level of B-content in last year's foliage seems to be about 3 ppm. However, levels should be higher when access to water is good, because droughts often reduce boron uptake. Levels should then at least be 9—10 ppm B for pine and spruce and 14—16 ppm B for birch.

Experiments with various doses of borax on selected boron-poor sites in 1977 pointed out optimum contents in last year's foliage as follows: Norway spruce and Scots pine 20—25 ppm B, lodgepole pine 25—30 ppm, *Betula* ssp. 28—33 ppm B. *Pinus sylvestris* showed toxicity symptoms when boron contents in last year's foliage exceeded 53 ppm. Optimum boron fertilizer dose is in the range from 1.5 to 2.0 kg B/ha under the conditions tested.

Boron deficient stands responded to borax fertilization, by increased uptake of boron and trees with recovery potentials turned to normal growth. Fertilizer with boron in different forms, did not influence the uptake rate. Imbalanced nutrient uptake on nutrient-poor fens and bogs, should be corrected by a compound fertilizer containing nitrogen, potassium, phosphorous and boron as main constituents.

A regional foliage sampling survey on experimental fields in South and Middle Norway was conducted in 1977—1978. Foliage (last year's) boron contents were above critical levels in a 20—60 km broad coastal belt. Inside there were suboptimum or deficient levels. This geographical pattern is similar to that observed for growth disturbances.

The specific indirect effects of boron deficiency with increased susceptibility to frost and water stress, explains why the large magnitude of B-deficiency in Norway has not been found earlier.

Introduction

From 1954 to 1972 about 200 afforestation trials were established on open nutrient poor peatland in Norway. Growth disturbances on these, especially at higher altitudes, were first observed in the late 1950's. Young *Picea abies* trees were frequently damaged by radiation frost in the growing season. In autumn or winter — early spring-periods, apical shoots were often killed by a combination of freezing and drying out. Susceptibility to frost seemed to increase with age of plants. Actually some of the plantations were partly or completely damaged within a 10-year-period.

In other trials, establishment was successful, but "shoot dieback" suddenly developed after 10—18 years of good growth. It seems as if water stress released this type of damage. The "dieback" symptoms on conifers have been similar to those described by Stone and Will (1965) for boron deficiency on *P. radiata* and *P. pinaster.*

The hypothesis that summer frost problems could partly be caused by improper boron nutrition, was first tested in 1968. Parallel to a microclimatic project dealing with radiation frost problems on afforested peatlands (Brække 1972), the effects of micronutrients were tested by spraying them directly on foliage. A positive, but not significant reduction of frost damage was measured on *P. abies* both at boron and manganese application (unpublished).

Rather spontaneously serious "shoot dieback" occurred in many older plantations on peatland in the spring and summer of 1974. In one fertilization trial on ombrogenous peat, the problems was studied closer. Extreme boron deficiency was found to be the physiological reason for "shoot dieback" on *P. abies, P. sylvestris* and *P. contorta* ssp. *latifolia* (Brække 1977).

Problems with imbalanced nutrient uptake and growth disturbances have also been reported for both younger and older peatland stands in Finland (Huikari 1974, 1977, Veijalainen 1975, 1978). Similar problems are noticed for some mineral soils there, as well. Boron deficiency is obviously one of the reasons for the growth disorder problems in Finland (Kolari 1979, Silfverberg 1979, 1980, Raitio 1979), but imbalanced uptake of other nutrients and stress factors else, might as well be important.

For *P. sylvestris* on mineral soils in Sweden Aronsson (1980) and Burgtorf (1981) have found growth disturbances coupled with low boron contents in needles. Growth disorders were mostly found when high doses of nitrogen had been added, and were especially serious on plots which were also limed.

Regional variation of foliage boron contents

In 1977—78 a regional survey with foliage sampling on *P. abies, P. sylvestris, P. contorta* ssp. *latifolia* and *Betula* spp. was accomplished. This is described by Brække (1979). The experiments selected for the study, were all established after 1954 and had all fertilizer treatments without boron. Last year's shoots in the upper one third of the crowns were collected from at least ten representative trees on each plot. Replications of samples on individual fields were pooled for each chosen treatment.

This study showed a close relationship between low boron contents in foliage and the mentioned problems with "frost" and/or "shoot dieback". In the region with problems, boron contents in last year foliage ranged from 1.4—4 ppm, 2.6—10 ppm, and 1.5—16 ppm for *P. abies, P. sylvestris,* and *Betula* spp. respectively.

In a 20—30 km broad zone inside the Oslofjord and the North Sea coastline low frequency of disturbed trees corresponded to relatively high boron levels in foliage. On the West coast and northwards, the zone seems to be 60—70 km broad. Inside this coastal belt, high probability for growth disturbances and low foliage boron contents were coupled (Fig. 1).

With respect to other nutrients, systematic higher contents of K, P, and Mn was found on sites with "disturbances" (see Table 1). This is explained by interruption of vital biochemical processes in foliage with accumulation of these elements at boron deficiency. Mg contents were opposite and showed a systematic positive correlation to boron contents. No significant differences between the two categories of sites were found for other nutrient elements (N, Ca, S, Fe, Zn, Cu).

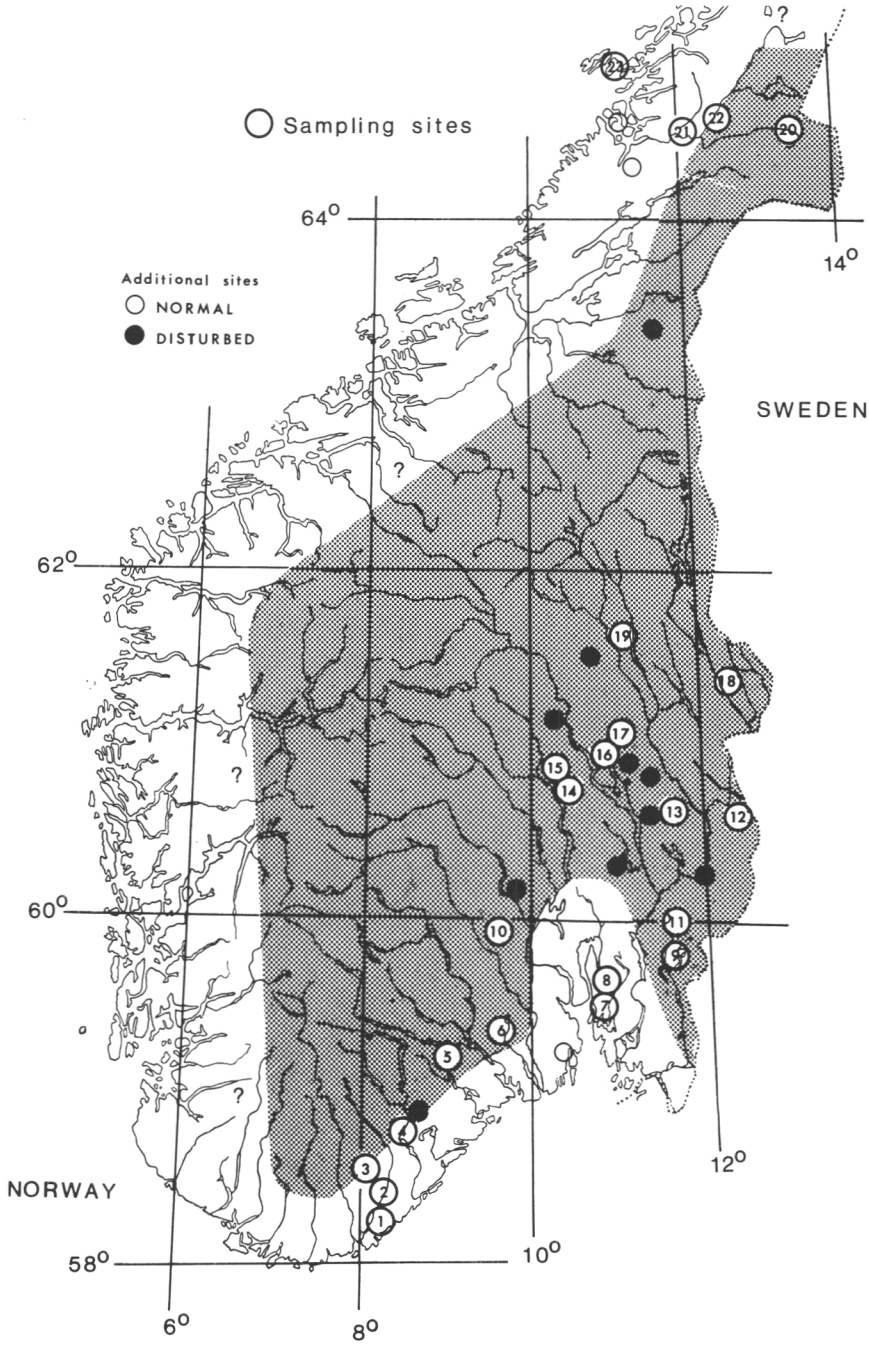


Figure 1. Geographical distribution of foliage sampling sites. Shaded area means that boron deficiency can be induced by afforestation on deep nutrient-poor peatland sites. (Modified after Brække 1979).

Table 1. Contents of K, Mg, P, B, Mn in last year's foliage from sampling sites 1—23 in Fig. 1. Data refer to plots where no boron fertilizer has been applied. Foliage were collected in Aug. — Oct. 1977—1978 (from Brække 1979).

Elements	Species							
	P. abies		*P. sylvestris*		*P. contorta*		*Betula* spp.	
	Category of plots[1]							
	1	2	1	2	1	2	1	2
	Number of plots							
	15	8	13	7	3	1	10	4
K %	0.60 ±0.04	0.57 ±0.06	0.51 ±0.02	0.47 ±0.03	0.50 ±0.05	0.44	0.80 ±0.06	0.71 ±0.11
Mg %	0.084 ±0.005	0.125 ±0.006	0.083 ±0.004	0.100 ±0.002	0.075 ±0.011	0.134	0.264 ±0.025	0.341 ±0.049
P %	0.178 ±0.010	0.160 ±0.013	0.153 ±0.006	0.129 ±0.007	0.134 ±0.028	0.137	0.298 ±0.027	0.164 ±0.036
B ppm	*2.3 ±0.18*	*10.6 ±1.22*	*5.1 ±0.60*	*11.5 ±1.17*	*7.5 ±0.24*	*17.6*	*8.3 ±1.52*	*21.3 ±2.69*
Mn ppm	338 ±67	208 ±58	259 ±52	119 ±25	298 ±111	225	1166 ±415	178 ±50

1) 1: Growth Disturbances
2: "Normal" growth

Table 2. Skøyenmyra site 11 in Fig. 1 (60°02′ N, 11°39′E, altitude 310 m). Boron dose-experimental in *Picea abies* with needle sampling on August 28. 1978 and October 1. 1980. Stand establishment 1962 with borax applied in May 1977.

Treatment	Year	%						ppm				
		N	K	Ca	Mg	P	S	B	Fe	Mn	Zn	Cu
1-control	1978	1.05	0.44	0.24	0.09	0.15	0.06	*3.2*	33	85	17.5	2.5
	1980	1.09	0.48	0.16	0.09	0.18	0.07	*2.3*	21	69	15.8	2.1
2 — $^1/_2B$[1]	1978	—	—	—	—	—	—	–	—	—	—	—
	1980	1.06	0.42	0.17	0.10	0.17	0.07	*13.5*	25	80	11.3	2.0
3—B	1978	1.11	0.56	0.22	0.10	0.17	0.07	*21.3*	37	70	20.6	2.1
	1980	1.12	0.58	0.14	0.10	0.22	0.07	*19.9*	23	89	16.3	2.0
4—2B	1978	1.21	0.50	0.25	0.09	0.16	0.07	*28.9*	36	70	17.9	2.0
	1980	1.11	0.42	0.19	0.11	0.18	0.07	*28.4*	21	66	15.4	1.8
5—3B	1978	1.19	0.47	0.15	0.09	0.15	0.08	*43.2*	26	65	11.9	2.6
	1980	1.25	0.49	0.12	0.09	0.19	0.08	*26.8*	21	56	11.9	2.3

1) B = 1.13 kg B/ha

Effects of borax fertilizer on nutrient uptake

Doses of borax fertilizer ranging from 5—30 kg/ha (0.56—3.39 kg B/ha) were applied to a *P. abies* plantation in May 1977 to test the effects on nutrient uptake (Table 2). Boron contents in the 1978 foliage increased curvilinearly in response to the doses given. The 10 kg borax dose (treatment 3-B) gave the greatest relative increase. Another sampling in 1980 showed that boron contents in current foliage had been rather stable up to 20 kg borax/ha (treatment 4-B), whereas at the highest dose a decrease was measured. This indicate that uptake at the highest dose had been beyond optimum range the first two or three years after application although no toxicity symptoms were observed on foliage.

The results from a similar experiment on *P. sylvestris* is given in Table 3. Trees on

Table 3. Njustmyra F.3 (60°17'N, 11°47'E, altitude 140 m). Boron dose-experiment in *Pinus sylvestris* with needle sampling on September 15. 1981. Stand establishment 1959 and borax (+NPK) applied in May 1980.

	Treatment		1 Control	2 +2B[1)]	3 +4B	4 +6B	F	LSD Fisher P≤5 %
		1980	1.62	1.63	1.65	1.66	0.15	—
N	% of dry matter	81	1.67	1.73	1.76	1.80	0.60	—
		1980	0.51	0.54	0.52	0.53	2.46	—
K	"	81	0.62	0.61	0.64	0.66	1.31	—
		1980	0.35	0.37	0.38	0.37	0.37	—
Ca	"	81	0.24	0.23	0.22	0.23	0.33	—
		1980	0.13	0.12	0.12	0.12	0.83	—
Mg	"	81	0.13	0.12	0.12	0.12	4.09*	0.01
		1980	0.16	0.16	0.15	0.15	0.78	—
P	"	81	0.20	0.20	0.20	0.19	1.42	—
		1980	0.12	0.12	0.12	0.11	0.28	—
S	"	81	0.12	0.12	0.12	0.11	1.41	—
		1980	9.8	78.5	118.9	163.7	166.76***	16.2
B	ppm	81	11.9	43.4	53.7	71.0	73.89***	9.2
		1980	64	62	68	68	0.75	—
Fe	"	81	42	45	46	43	1.38	—
		1980	355	458	367	440	1.52	—
Mn	"	81	275	314	244	290	2.36	—
		1980	55	52	55	50	0.80	—
Zn	"	81	60	51	54	53	2.28	—
		1980	2.8	2.6	2.5	2.6	2.47	—
Cu	"	81	3.2	2.7	2.8	2.8	2.47	—

1) B = 1.13 kg B/ha

control plots had boron contents at the lower range for normal growth. Borax fertilizer at doses from 20 (2B) to 60 (6B) kg/ha (2.26—6.78 kg B/ha) gave drastic responses with respect to uptake. In 1981 most trees on plots with 40 and 60 kg borax/ha partly shed their needles from previous years (1980). Symptoms of toxicity in the last year's foliage (1981) were found at doses 40 and 60 kg borax/ha (4.52—6.78 kg B/ha).

The needle analyses showed that shedding of older needles occurred at B content > ca. 115 ppm. Symptoms of toxicity in last year's foliage started when needle boron contents reached 53 ppm and increased in extent at higher contents (Fig. 2). When boron contents were below 50 ppm, the foliage had normal outlook. Contents of other nutrients were not altered significantly by the treatments, except Mg which was somewhat reduced at increased borax doses.

Boron uptake after application of compound fertilizer and liming

The effects of very small and larger doses of boron combined with different complex fertilizers and liming are given in Table 4. A Ca-Mg antagonism is clear, and a systematic decrease in Ca-contents was found when only dolomite was applied. Except for treatment 2 boron uptake was less when ground limestone and dolomite had been applied.

The infinite dose of 0.12 kg B/ha applied with N, K, and P in 1976, could be traced as higher boron contents in foliage three

Table 4. Kjølamyra site 13, in Fig. 1 (60°37'N, 11°44'E, altitude 410 m). Characteristics of needle samples collected on August 30. 1978 in an 18-year-old *P. abies* plantation after different fertilization treatments (from Brække 1979).

Elements / Treatment			%		ppm
			Ca	Mg	B
1— K 96 kg/ha, P 30 " "	(1976)	a	0.29	0.100	1.3
		b	0.22	0.111	1.8
		x̄	0.26	0.106	1.5
2— N 82 kg/ha, K 94 " ", P 36 " ", B 0.12 " "	(1976)	a	0.28	0.133	3.7
		b	0.20	0.142	2.8
		x̄	0.24	0.138	3.2
3— K 96 kg/ha, P 30 " ", B 1.13 "	(1976)	a	0.31	0.108	17.8
		b	0.24	0.128	26.9
	(1977)	x̄	0.28	0118	22.4
4— N 82 kg/ha, K 94 " ", P 36 " ", B 1.25 "	(1976)	a	0.26	0.120	18.2
		b	0.23	0.134	20.1
	(1977)	x̄	0.25	0.127	19.1

a: + 400 kg Ca — 64 kg Mg/ha (ground limestone and dolomite)
b: + 105 kg Ca — 65 kg Mg/ha (dolomite)

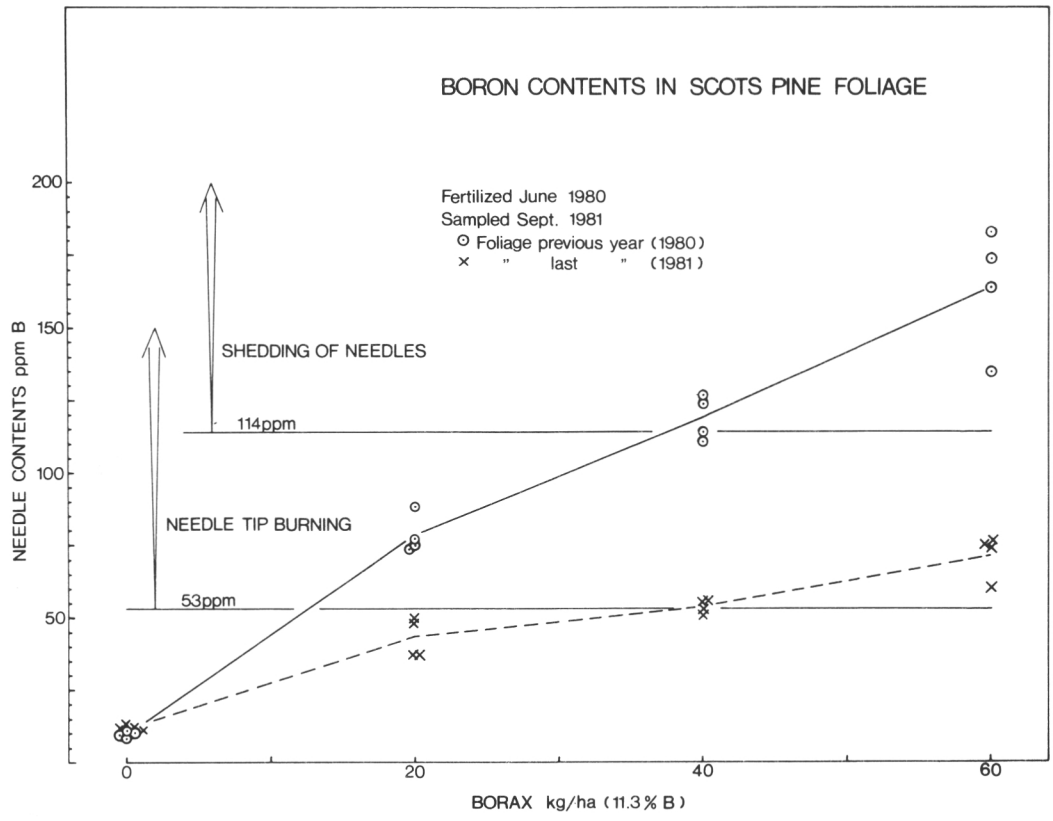


Figure 2. Njustmyra F.3 (60°17' N, 11°47' E, altitude 140 m). Boron contents in foliage of Scots pine at various borax doses.

growing seasons later. However, it did not raise contents to physiologically safe levels. The commercial NPK-complex fertilizer used on afforested peatland in Norway has this dose as standard (0.02 % B). Extra addition of 1.3 kg B/ha as borax in spring 1977, increased boron content to 19.1 ppm B.

Growth response to boron fertilization

Characteristic for boron deficiency is that the symptoms are released indirectly by physiological stress factors related to climate and/or soil. Shifts from severe damage due to low boron uptake in one year to normal development and growth some years later, frequently occur. This might be explained by natural changing of boron availability in root zone over time and that susceptible plant tissue due to low boron content, at moderate or low stress avoids irreversible damage.

The following tables demonstrate some of these points. Table 5 shows that 7 % of the plants with boron deficiency has recovered also on control plots in the 4-year-period after 1976. Borax has improved recovery, and at 30 kg borax/ha 19 % of original plant number have recovered to normal. The response in height growth to boron applications, however, was slightly positive for *P. abies.*

The results from another experiment given in Table 6, show that recovery has been much larger at PK than at NPK both with and without extra boron. The main reason for this is the small standard dose of boron in the NPK-fertilizer. This has kept the percentage of growing plants relatively high. On an average for all treatments, borax applied at 10 kg/ha in spring 1977, has increased the percentage of growing trees with 24 %. The corresponding response in height growth for the 5-year-period 1976—1981 is 30 cm (Table 7). The response might be somewhat underestimated because tree height refers to normal growing trees which means that more recovered trees were measured in 1981 at borax fertilization.

In the years 1974—1976 serious boron deficiency was observed on Njustmyra for plots without borax fertilizer, "Ast — B". Table 8 shows that percentages of normal growing *P. sylvestris* and *P. contorta* trees were reduced on all plots from 1972 to 1980 irrespective treatments. However, this reduction was larger on plots without borax, and averaged for all tree species it was about 5 %. Figure 3 shows that boron deficiency did hurt the trees seriously, especially *P. sylvestris* and *P. abies.* After 1977 the stands have recovered and corrected losses mostly due to complete death, were only 3—6 %.

Up to 1974 trees on "Ast — B" plots grew somewhat better, even significant for *P. contorta,* than on "Ast". In the period 1974—1980 these trends have changed and total heights for *P. sylvestris* and *P. abies* were somewhat less on "Ast — B" plots. *P. contorta* on "Ast — B" plots were still leading in total heights, but not at significant level.

Table 5. Skøyenmyra site 11 in Fig. 1 (60°02'N, 11°39'E, altitude 310 m). Growth response of *Picea abies* at various doses of boron fertilizer. Fertilizer borax applied in May 1977.

			1 Control	2 +½B[1]	3 +B	4 +2B	5 +3B
% normal growing of total planted in 1962	Autumn	1976	72	76	72	71	65
	"	1980	79	87	86	87	84
	Change		+7	+11	+14	+16	+19
Tree height m	Autumn	1976	2.62	2.90	2.29	3.19	2.97
	"	1980	3.51	3.96	3.33	4.22	3.92
	Growth response		0.89	1.06	1.04	1.03	0.95

[1] B = 1.13 kg B/ha

Table 6. Kjølemyra site 13 in Fig. 1 (60°37'N, 11°44'E, altitude 410 m). Response of young boron deficient *Picea abies* stands to boron application as fertilizer borax. Results are given in percentage normal growing plants of the original number planted.

			At planting in June 1961								
			No rawphosphate				Rawphosphate on roots				
			Fertilization treatments								
			PK		NPK (0.12 kg B/ha)		PK		NPK (0.12 kg B/ha)		Mean
			Ground limestone-dolomite 1972[1])								
			a	b	a	b	a	b	a	b	
1.13 kg B/ha in spring 1977	Autumn	1976	9	8	79	85	19	39	90	100	54
	"	1981	55	63	93	81	60	83	89	91	77
	Change		+46	+55	+14	— 4	+41	+44	— 1	— 9	+23
Control	Autumn	1976	12	3	84	92	29	13	99	92	53
	"	1981	25	24	71	80	21	39	84	72	52
	Change		+13	+21	—13	—12	— 8	+26	—15	—20	— 1
Increase in percentage at B-fertilization			+33	+34	+27	+ 8	+49	+18	+14	+11	+24

1) a: + 800 kg Ca — 128 kg Mg/ha (ground limestone and dolomite)
b: + 210 kg Ca — 130 kg Mg/ha (dolomite)

Table 7. Kjølamyra site 13 in Fig. 1 (60°37'N, 11°44'E, altitude 410 m). Growth response of young boron deficient *(Picea abies)* stand to boron application as fertilizer borax. Results are given as mean height and period growth in meters.

			At planting in June 1961								
			No rawphosphate				Rawphosphate on roots				
			Fertilization treatments								
			PK		NPK (0.12 kg B/ha)		PK		NPK (0.12 kg B/ha)		Mean
			Ground limestone-dolomite 1972[1])								
			a	b	a	b	a	b	a	b	
1.13 kg B/ha in spring 1977	Autumn	1976	0.96	1.44	3.75	3.13	1.71	2.08	3.98	4.19	2.66
	"	1981	2.86	3.12	5.42	4.54	2.68	3.06	5.53	5.31	4.07
	Period growth		1.90	1.68	1.67	1.41	0.97	0.98	1.55	1.12	1.41
Control	Autumn	1976	1.85	2.14	3.61	3.56	2.01	2.47	3.99	3.73	2.92
	"	1981	2.82	2.39	5.46	4.54	3.25	3.21	5.36	5.22	4.03
	Period growth		0.97	0.25	1.85	0.98	1.24	0.74	1.37	1.49	1.11
Growth response at B-fertilization			+0.93	+1.43	—0.18	+0.43	—0.27	+0.24	+0.18	—0.37	+0.30

1) a: + 800 kg Ca — 128 kg Mg/ha (ground limestone and dolomite)
b: + 210 kg Ca — 130 kg Mg/ha (dolomite)

Fertilization of nitrogen and boron poor stands

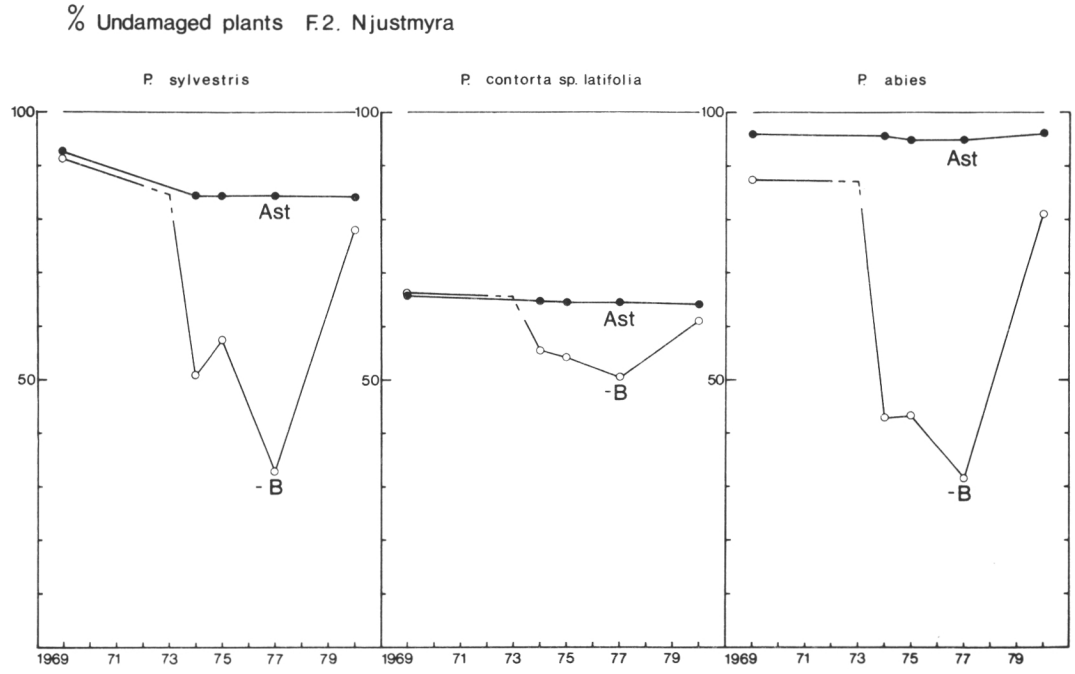
It is rather common that inland *P. abies* plantations on poor fens in Norway suffer both from nitrogen and boron deficiency some years after fertilizer has been given. To study the effect of different fertilizer types to correct this imbalance, and especially the interaction on N- and B-uptake, an experiment with 14 treatments were established in 1980 (see Table 9).

Treatment 1 which is the control, shows that *P. abies* on this site has low contents of nitrogen and boron in last year needles. Phosphorus and potassium are at good levels. Application of increasing N-doses (82—246 kg N/ha, Treatms. 2—4) at fixed boron dose,

Table 8. Njustmyra F.2 (60°17'N, 11°47'E, altitude 140 m). Fertilizer minus experiment with *Pinus sylvestris. Pinus contorta* ssp. *latifolia* and *Picea abies.* The Ast-B treatment means application of all necessary elements except boron (minus boron).

			Pinus sylvestris		*Pinus contorta* v. *latifolia*		*Picea abies*	
			Ast[1]	Ast-B	Ast	Ast-B	Ast	Ast-B
% normal growing trees of total number planted in 1957	Autumn	1972	87	86	65	65	96	87
	"	1980	84	78	64	61	96	81
	Period change		— 3	— 8	— 1	— 4	0	— 6
Tree heights m	Autumn	1972	3.41	3.60	3.79	4.39	1.60	1.90
	"	1980	6.19	5.63	7.27	7.82	2.79	3.05
	Period growth m		2.78	2.03	3.48	3.43	1.19	1.15

1) Ast means: 30 kg/ha fertilizer borax in 1957 (3.5 kg B/ha) together with other necessary elements



Figur 3. Njustmyra F.2 (60°17′ N, 11°47′ E, altitude 140 m). Fertilizer minus experiment. "Ast" means a complex balanced fertilizer. "—B" means that this element is omitted from "Ast". % undamaged plants is of original number of plants at establishment in 1957.

raised N-content to 1.58 % and B-content to about 20 ppm, whereas potassium was reduced to a suboptimum level (0.39 % K). Phosphorus and potassium (Treatm. 5) raised N, K, and P, but reduced B to deficiency range. When boron was also added (Treatm. 6), N-content was reduced to 1.13 % and B-content raised to 23 ppm. In Treatment 7 where compound NPK-fertilizer with 0.02 % B was applied, N was raised to 1.29 % and B to 5.3 ppm. Increase of B to full dose (Treatms. 7—10) raised the contents of this element to about 21 ppm B while the contents of N stayed rather stable. The nitrogen and boron were applied as granulated NH_4NO_3 with boron. Boron applied as borax (Treatm. 11) or fritted to silica as FTE 11 and FTE 26 (Treatms. 12—13), did

Table 9. Kultemyra (60°21'N, 10°53'E, altitude 480 m). Characteristics of needle samples collected on October 30. 1981 from *Picea abies* after different fertilization treatments. (1) refers to a 21-year old plantation, (2) refers to natural regeneration.

		%				ppm			
		N	K	P	B	Fe	Mn	Zn	Cu
1 — Control (unfertilized spring 1980)	(2)	*1.16*	0.55	0.17	*3.4*	20	151	21.6	1.7
2 — N, B (NH_4NO_3 with boron)	"	*1.25*	0.49	0.18	*22.1*	21	118	15.5	1.8
3 — 2N, B (------ " ------)	"	*1.48*	0.49	0.16	*23.7*	21	158	17.2	1.7
4 — 3N, B (------ " ------)	"	*1.58*	0.39	0.19	*20.7*	19	135	21.3	1.8
5 — K, P (Compound PK-fertilized, PK 5—16)	(1)	*1.29*	0.70	0.20	*2.4*	26	251	30.0	2.3
6 — K, P + B (Borax 11.3 % B)	"	*1.13*	0.83	0.19	*23.0*	19	189	24.9	2.0
7 — N, K, P, 0.07 B (Compound NPK-fertilizer, NPK 14-6-16)	"	*1.29*	0.81	0.19	*5.3*	21	194	22.5	2.0
8 — N, K, P, 0.33 B (NH_4NO_3 with boron)	"	*1.29*	0.73	0.19	*14.6*	22	281	29.9	2.1
9 — N, K, P, 0.57 B (---- " ----)	"	*1.40*	0.84	0.22	*19.0*	25	296	28.7	2.2
10 — N, K, P, B (---- " ----)	"	*1.28*	0.65	0.18	*20.8*	21	140	21.1	2.1
11 — N, K, P + B (Borax 11.3 % B)	"	*1.28*	0.78	0.19	*18.9*	23	324	24.6	2.2
12 — N, K, P + B (FTE 11)	"	*1.28*	0.65	0.17	*23.2*	21	139	21.3	1.9
13 — N, K, P + B, "Micro" (FTE 26)	"	*1.27*	0.72	0.18	*19.8*	24	187	24.4	1.9
14 — 2N, K, P, B (NH_4NO_3 with boron)	"	*1.37*	0.72	0.19	*22.1*	23	177	21.0	2.0

N = 82 kg/ha
K = 96 "
P = 30 "
B = 1.72 "

Micro = 4.48 kg Fe, 1.92 kg Mn, 1.28 kg Zn, 0.64 kg Cu, 0.032 kg Mo/ha

not alter the boron uptake. Although FTE 26 also contained Fe, Mn, Zn, and Cu, this did not improve uptake of these elements. Actually did none of the treatments alter contents of these four micronutrients systematically.

Judged from the nutrient uptake data, Treatment 14 has probably given the Norway spruce trees the best nutrient balance in needles on the poor fen, which was tested. The treatment included the following application rate: 164 kg N, 96 kg K, 30 kg P, 1.72 kg B/ha.

Conclusions

Boron deficiency on peatland in Norway is only reported for fertilized stands. Growth disturbances in such stands are most likely released by low temperatures which cause frost damage and by water stress. This actually explains why the large magnitude of B-deficiency in Norway has not been discovered earlier.

It is reason to expect that low foliage boron content will become a problem after afforestation on most nutrient-poor deep peatland sites in the shaded area on Figure 1. "Shoot dieback" is also noticed in naturally regenerated forest stands on peatland.

A close relationship was found between B and Mg. Nearly everywhere low B-contents corresponded to low Mg-levels in foliage. Application of boron at optimum doses often raised Mg-contents although this element was not applied. The most reliable explanation is that boron deficiency influences uptake and/or cycling of Mg in trees.

Experiments with various doses of boron to coniferous stands give reason to recommend these below 2.5 kg B/ha to avoid serious toxicity. Optimum doses are supposed to be between 1.5—2.0 kg B/ha, which probably will be sufficient for 20 years of good growth. *P. sylvestris* stands showed clear symptoms of toxicity at 4.5 kg B/ha (Fig. 2).

With respect to boron contents in last year's foliage, some key figures are listed in Table 10. It is characteristic that the range for optimum contents in foliage is narrow. The trees also need a "bufferzone" above deficiency limit to avoid irreversible damage in periods with restricted boron uptake. Therefore boron contents at about 8 ppm in needles under normal growing conditions, should be required. When meristems are active, trees will need continous supply of boron. In periods with water stress, uptake of boron is restricted. As boron is immobile in trees, deficiency may develop suddenly in the meristems when uptake rate is too close to deficiency level beforehand.

Table 10. Levels for boron contents in last year's foliage (ppm) at deficiency, optimum range, and toxicity.

	Pinus sylvestris *P. contorta* ssp. *latifolia* *Picea abies*	*Betula* spp.
Deficiency	< 3	< 3
Lowest acceptable limit	8	(14)
Possible optimum range	20—30	30
Toxic range	>53[1)]	—

1) Refer to *P. sylvestris*

Growth data shows that boron deficiency at serious levels disturbs apical dominance of the trees. However, such trees may usually keep their recovery potentials for some time.

The boron deficiency problems seems to change in severity from year to year on a particular field. After 1977 some of the boron poor fields have recovered somewhat without boron fertilization. This is reflected in Tables 5—8 and in Figure 3. Despite this, boron fertilization has improved recovery to normal growth, although it has not improved height growth much. The best response was found for *P. sylvestris* with about 10 cm extra height growth per year, and the least for *P. contorta* with practically no response.

The conclusion to this should be that ability to avoid damage at boron deficiency, differ for species. Trees can also grow nearly normal at low boron uptake when climatic or edaphic stress is low. A severe drought for example, can release acute damage for such trees. Susceptibility to damage vary within the population of the same species, and trees which are not hurt, seems to continue growth near normal.

Refertilization of stands which have imbalanced nutrient uptake, oppose problems like: choise of elements which should be applied, chemical forms of elements and required doses.

Different boron fertilizers like solubor granulated to NH_4NO_3, borax (11.3 % B), boron fritted to silica, FTE 11, FTE 26, gave about equal effects on uptake.

Application of all other micronutrients did not result in measureable uptake response which should indicate that Fe, Mn, Zn, Cu, and Mo were not at suboptimum levels before fertilization.

Optimum doses at refertilizing young stands on poor fens which have low foliage contents of nitrogen and boron are close to: 164 kg N, 96 kg K, 30 kg P, and 1.7 kg B/ha. A compound fertilizer with these nutrients at the mentioned doses proved to give a proper correction of the imbalanced nutrient status.

References

ARONSSON, A. 1980. Frost hardiness in Scots pine (*Pinus silvestris* L.). II. Hardiness during winter and spring in young trees of different mineral nutrient status. Stud. For. Suec. 155: 1—27.

BRAEKKE, F.H. 1972. Varmehusholdning og mikroklima på ulike myrtyper. (Energy balance and micro-climate on different peatland vegetation types.) Meddr norske SkogforsVes. 30: 1—134.

— 1977. Fertilization for balanced mineral nutrition of forests on nutrient-poor peatland. Suo 28: 53—61.

— 1979. Boron deficiency in forest plantations on peatland in Norway. Medd. Nor. inst. skogforsk. 35:213—236.

BURGTORF, H. 1981. Effekten av växtnäringstillförsel till några tallbestånd på näringsfattig mark i kyliga klimatlägen (The effects of supply of plant nutrients to some pine stands on poor and cold sites). Rapp. skogsekol. skogl. marklära 37:1—34.

HUIKARI, O. 1974. Hivenravinteet ja puiden kasvu. [Micronutrients and tree growth.] Metsä ja Puu 11: 28—29.

— 1977. Micro-nutrient deficiencies cause growth disturbances in trees. Silva Fenn. 11:251—255.

KOLARI, K.K. 1979. Hivenravinteiden puute metsäpuilla ja männyn kasvuhäiriöilmiö Suomessa — kirjallisuuskatsaus. Abstract: Micro-nutrient deficiency in forest trees and dieback of Scots pine in Finland — a review. Folia For. 389:1—37.

RAITIO, H. 1979. Boorin puutteesta aiheutuva männyn kasvuhäiriö metsitetyllä suopellolla. Oireiden kuvaus ja tulkinta. Abstract: Growth disturbances of Scots pine caused by boron deficiency on an afforested abandoned peatland field. Description and interpretation of symptoms. Folia For. 412:1—16.

SILFVERBERG, K. 1979. Männyn kasvuhäiriön ajoittuminen ja alkukehitys turvemaan boorinpuutosalueella. Abstract: Phenology and initial development of a growth disorder in Scots pine on boron deficient peatland. Folia For. 396:1—19.

— 1980. Kuusen kasvuhäiriö ja hivenravinteet. Abstract: Micronutritional growth disorder in Norway spruce. Folia For. 432:1—13.

STONE, E.L. & WILL, G.M. 1965. Boron deficiency in *Pinus radiata* and *P. pinaster*. Forest Sci. 11: 425—433.

VEIJALAINEN, H. 1975. Kasvuhäiriöistä ja niiden syistä metsäojitusalueilla. Summary: Dieback and fertilization on drained peatlands. Suo 26:87—92.

— 1978. Metsäpuiden latvakadon esiintymisestä Suomessa. Summary: Occurrence of dieback of forest trees in Finland. Metsäntutkimuslaitoksen suontutk. osaston tiedonantoja 1:1—22.

Total of 14 references

CONTRIBUTED PAPERS

OCCURRENCE OF GROWTH DISTURBANCE SYMPTOMS ON DIFFERENT PEATLAND SITES IN FINLAND

Jukka Laine and Pasi Puttonen

An extensive research project with an aim to investigate the present condition of forest drainage objectives, and the economical results thereof, was started in the University of Helsinki in 1979 and financed by the Academy of Finland; the field work was completed in 1981. The data obtained also presented an opportunity to study the possible occurrence of growth disturbance symptoms in the drained peatland forests.

The data consists of over 5700 sample plots measured systematically with random start on randomly selected peatland areas. Geographically the data covers the whole area of large scale forest drainage activities in this country and the geographical units in this research project were again randomly selected.

Allocation of sample plots according to drainage age, geographical area and ownership group was determined in relation to their corresponding share of the total drained area.

The number of sample plots possessing visible growth disturbance symptoms in the data is relatively small, ca. 2 % of the entire data. In sites with no fertilization the proportion was as low as 1 % whereas in fertilized plots the corresponding value was 4 %. Most of the growth disturbance cases (more than 70 %) were located in northern Finland irrespective of whether fertilized or unfertilized were considered.

The open, treeless mires and above all certain wet pine mire types (mosaic sites with pronounced open mire features) turned out to be rather susceptible to growth disturbances (in the fertilized data of certain site types the proportion was over 10 %). In the data of naturally tree covered, so called genuine spruce and pine mires, growth disturbances were rarely observed, only 0.3 % of the unfertilized cases and 1.4 % of the fertilized sample plots.

Introduction

Since the latter half of the 1970s observations and analyses have been published concerned with the growth disturbances of forest trees, phenomenon which seem to occur most frequently in drained and fertilized peatlands (e.g. Huikari 1974, Veijalainen 1975).

The symptoms of the growth disturbance are most clearly observed as: disorders in height growth, leader shoot dieback, loss of apical dominance and, as a final stage, death of the tree. Macro- and microscopic symptoms of the phenomenon have been described, for instance, by Raitio and Rantala (1977) as regards Scots pine *(Pinus sylvestris* L.) and by Silfverberg (1980) as regards Norway spruce *(Picea abies* L.). The visible symptoms of growth disturbances have been described to be rather similar in all native forest trees.

Micronutrient deficiencies (especially that of boron) have been generally reported to be the most probable causes for the observed disturbances (e.g. Huikari 1974, Veijalainen 1975, Raitio and Rantala 1977, Silfverberg 1980).

An extensive research project with an aim to investigate the present condition of forest drainage objectives, and the economical results thereof, was started in the University of Helsinki in 1979 and financed by the Academy of Finland; the field work was completed in 1981. The data collected also presented an opportunity to study the occurrence of growth disturbance symptoms in the drained peatland forests, their regional distribution and effects of site type and fertilizer application.

Material and methods

A multi-stage sampling was used in the study. At the first stage the country was divided into five areas, within which subareas (shaded areas in Fig. 1) were randomly selected. At the second stage a sample of drainage areas was systematically selected from the population of drained peatlands in each area. Drained peatland units to be studied and, subsequently sample plots, were allocated to study areas, drainage age and ownership groups in relation to their corresponding share of the total drained area. The third stage consisted of locating and measuring the sample plots in the field, systematically spaced at 200 m intervals, and with random start, along the inventory transects (ca.1 km/50 ha of drained peatland) randomly located and marked on the maps.

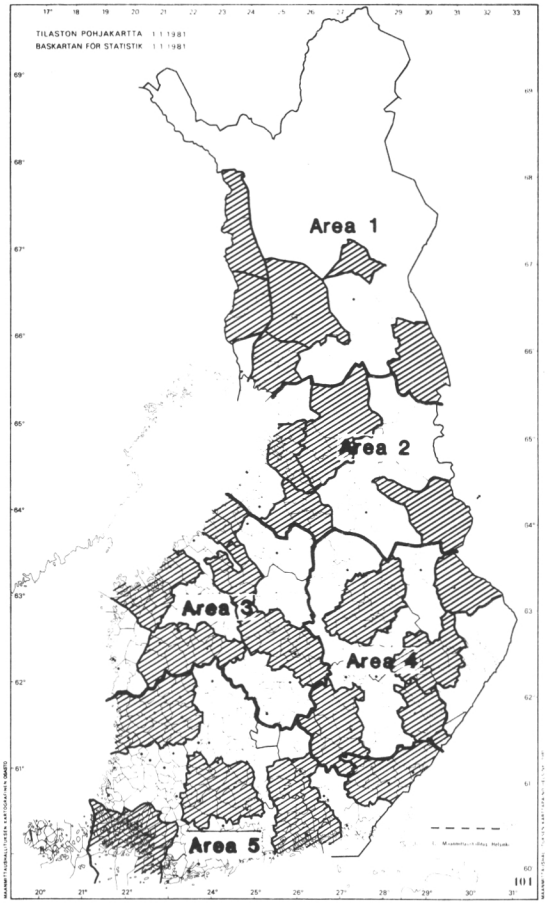


Figure 1. The areal division used in the study. The shaded parts in each numbered area were randomly selected for the inventory.

Besides the standard tree stands measurements, the original site type was determined and the occurrence of visible growth disturbance symptoms was recorded. Whether the sample plot had been fertilized or not was evaluated from field observations.

The measured data consists of 5776 sample plots from drained peatlands covering the major mire site types that have been considered economical to drain for forestry purposes during the four decades under study (Table 1).

Results and discussion

The number of observed growth disturbance cases in the whole data was relatively small; only 35 sample plots (1 %) in the

Table 1. Distribution of the study material according to site type, age of drainage and fertilizer treatment. For site type abbreviations and descriptions see Heikurainen and Pakarinen 1982.

Site type	Age class of drainage 1930—50 n1)	n2)	%3)	1951—60 n1)	n2)	%3)	1961—70 n1)	n2)	%3)	1971—77 n1)	n2)	%3)	All n1)	n2)	%3)
Group 1.4)															
LhK	26	1	4	16	0	0	20	0	0	14	0	0	76	1	1
RhK	62	1	2	36	1	3	50	8	16	39	4	10	187	14	7
MK	102	8	8	53	4	8	60	5	8	41	7	17	256	24	9
PK (MrK)	31	4	13	31	7	23	51	11	22	29	11	38	142	33	23
KgK	79	10	13	48	4	8	89	27	30	86	19	22	302	60	20
PsK (RäK)	8	1	13	5	1	20	31	12	39	24	8	33	68	22	32
KR	53	8	15	33	12	36	113	57	50	54	18	33	253	95	38
PsR	23	6	26	39	18	46	162	93	57	94	49	52	318	166	52
KgR	94	26	28	98	27	28	235	92	39	145	54	38	572	199	35
VkR	8	0	0	14	2	14	14	10	71	14	10	71	50	22	44
IR	24	9	38	25	9	36	78	37	48	46	21	46	173	76	44
TR	23	3	13	40	16	40	103	51	50	141	83	59	307	153	50
RaR	3	2	67	9	4	44	21	9	43	27	22	81	60	37	62
Group 2.4)															
VLK (LK)	4	1	25	17	2	12	20	2	10	2	0	0	43	5	12
KoLK (KoL)	9	0	0	4	0	0	1	0	0	1	0	0	15	0	0
RhSK (RhNK)	27	3	11	17	3	18	44	13	30	28	7	25	116	26	22
VSK (VNK)	12	0	0	6	1	17	28	9	32	16	6	38	62	16	26
Group 3.4)															
VLR (LR)	19	6	32	39	9	23	41	19	46	17	11	65	116	45	39
RLR (RL)	11	4	36	12	2	17	46	19	41	23	8	35	92	33	36
RhSR (RhNR)	75	24	32	62	11	18	132	66	50	67	25	37	336	126	38
VSR (VNR)	163	33	20	133	42	32	289	139	48	149	70	47	734	284	39
TSR (TNR)	59	21	36	63	24	38	196	114	58	132	83	63	450	242	54
LkR	31	12	39	50	27	54	204	107	52	171	91	53	456	237	52
Group 4.4)															
VL	8	1	13	1	0	0	12	5	42	6	3	50	27	9	33
RiL	7	1	14	2	0	0	4	1	25	0	0	0	13	2	15
RhSN	24	2	8	8	1	13	46	28	61	34	12	35	112	43	38
VSN	35	9	26	17	3	18	101	52	51	60	27	45	213	91	43
LkKaN	14	2	14	11	1	9	43	22	51	46	22	48	114	47	41
LkN	6	3	50	13	4	31	40	17	43	19	11	58	78	35	45
RaN	1	0	0	0	0	0	7	2	29	2	1	50	10	3	30
RiN	2	1	50	0	0	0	8	2	25	15	7	47	25	10	40
All	1043	202	19	902	235	26	2289	1029	45	1542	690	45	5776	2156	37

1) total number of sample plots
2) number of fertilized sample plots
3) proportion of fertilized sample plots
4) Group 1. = genuine, originally treecovered site types having only pine or spruce mire features; Group 2. = mosaic site types having both spruce mire and treeless mire features; Group 3. = mosaic site types having both pine mire and treeless mire features; Group 4. = treeless mire types in natural condition.

unfertilized and 85 (3.9 %) in the fertilized data (Table 2).

Most of the sample plots with growth disturbance symptoms (c. 60 %) were found in peatlands drained in 1960s, whereas the data of the oldest age class had the smallest proportion (8 % of all the observed cases, Table 2). The fertilization of drained peatlands, which radically increased in 1960s, is a probable cause for the result mentioned, but also the shift of drainage activities to site types that, according to the results of this study, are more susceptible to growth disturbances, had its effect.

The least number of growth disturbance cases were associated with so called *genuine* spruce or pine mire site types. These site types possess features of only one of the main site type categories (see Heikurainen and Pakarinen 1982) and have a tree stand already in natural condition before drainage (Group 1 in Table 2). The proportion of plots with disturbances in this case was only 0.3 % in the unfertilized and 1.4 % in the

Table 2. Distribution of sample plots with observed growth disturbance symptoms according to site type, age of drainage and fertilizer treatment. Grouping of site types as in Table 1.

Site type	Age class of drainage																All			
	1930—50				1951—60				1961—70				1971—77							
	n1)	%2)	n3)	%4)	n1)	%2)	n3)	%4)	n1)	%2)	n3)	%4)	n1)	%2)	n3)	%4)	n1)	%2)	n3)	%4)
Group 1.																				
LhK	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RhK	—	—	—	—	1	2.9	—	—	—	—	1	12.5	—	—	—	—	1	0.6	1	7.1
MK	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
PK (MrK)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
KgK	—	—	—	—	—	—	1	25.0	—	—	1	3.7	—	—	—	—	—	—	2	3.3
PsK (RäK)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	12.5	—	—	1	4.5
KR	—	—	—	—	—	—	—	—	1	1.8	1	1.8	—	—	—	—	1	0.6	1	1.1
PsR	—	—	—	—	—	—	—	—	1	1.4	2	2.2	—	—	—	—	1	0.6	2	1.3
KgR	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
VkR	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
IR	—	—	—	—	—	—	1	11.1	1	2.4	—	—	1	4.0	—	—	2	2.1	1	1.3
TR	—	—	1	33.3	—	—	—	—	—	—	3	5.9	—	—	1	1.2	—	—	5	3.3
RaR	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Group 2.																				
VLK (LK)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
KoLK (KoL)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RhSK (RhNK)	—	—	—	—	—	—	—	—	—	—	1	7.7	—	—	—	—	—	—	1	3.8
VSK (VNK)	1	8.3	—	—	—	—	—	—	—	—	—	—	—	—	—	—	1	2.2	—	—
Group 3.																				
VLR (LR)	—	—	—	—	4	13.3	—	—	1	4.5	2	10.5	—	—	—	—	5	7.0	2	4.4
RLR (RL)	—	—	1	25.0	—	—	—	—	1	3.7	2	10.5	1	6.7	2	25.0	2	3.4	5	15.2
RhSR (RhNR)	—	—	3	12.5	1	2.0	2	18.2	1	1.5	10	15.2	1	2.4	—	—	3	1.4	15	12.0
VSR (VNR)	—	—	2	6.1	4	4.4	—	—	1	0.7	15	10.8	—	—	5	7.1	5	1.1	22	7.7
TSR (TNR)	—	—	—	—	3	7.7	2	8.3	3	3.7	9	7.9	1	2.0	1	1.2	7	3.4	13	5.4
LkR	—	—	—	—	—	—	—	—	1	1.0	1	0.9	1	1.3	—	—	2	0.9	1	0.4
Group 3.																				
VL	—	—	—	—	—	—	—	—	1	14.3	2	40.0	—	—	2	66.7	1	5.5	4	44.4
RiL	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RhSN	—	—	—	—	—	—	—	—	1	5.6	3	10.7	1	4.5	—	—	2	2.9	3	7.0
VSN	1	3.8	1	11.1	—	—	—	—	—	—	2	3.8	—	—	—	—	1	0.8	3	3.3
LkKaN	—	—	—	—	—	—	—	—	1	4.8	2	9.1	—	—	1	4.5	1	1.5	3	6.4
LkN	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RaN	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
RiN	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
All	2	0.2	8	4.0	13	1.9	6	2.6	14	1.1	57	5.5	6	0.7	13	1.9	35	1.0	85	3.9

1) number of sample plots with growth disturbance symptoms in unfertilized data
2) proportion of growth disturbances in unfertilized data
3) number of sample plots with growth disturbance symptoms in fertilized data
4) proportion of growth disturbances in fertilized data

fertilized data. Growth disturbances were most frequently found in the data of originally (before drainage) treeless site types (2.2 %) and highest of all (2.6 %) in the material of site type group 3 in Table 2, which is comprised of mosaic sedge pine mire types having pronounced treeless mire features and are wet sites in natural condition having only sparse tree stand of pine and birch before drainage. Results by Heikurainen (1982) show similar site type — growth disturbance relationships.

Fertilization greatly increased the risk for growth disturbances in all the site type groups (Table 2). This may be due to the improved growth (increased dry matter production) and the subsequent dilution of micronutrient concentrations in the biomass (e.g. Veijalainen 1977).

The frequency of growth disturbances showed marked regional differences. Nearly three quarters (74 %) of the plots with disturbances were located in areas 1 and 2 in northern Finland (Fig. 1) whereas in the

Table 3. Distribution of unfertilized and fertilized sample plots with growth disturbance symptoms according to study area.

		Area 1	2	3	4	5	Whole country
Number of unfertilized sample plots	1)	618	773	832	831	566	3620
	2)	5	22	3	5	1	36
	3)	0.8	2.8	0.4	0.6	0.2	1.0
Number of fertilized sample plots	1)	377	632	480	362	305	2156
	2)	33	29	13	6	4	85
	3)	8.8	4.6	2.7	1.7	1.3	3.9
All	1)	995	1405	1312	1193	871	5776
	2)	38	51	16	11	5	121
	3)	3.8	3.6	1.2	0.9	0.6	2.1

1) total number
2) number of observed growth disturbances
3) proportion of growth disturbances, %

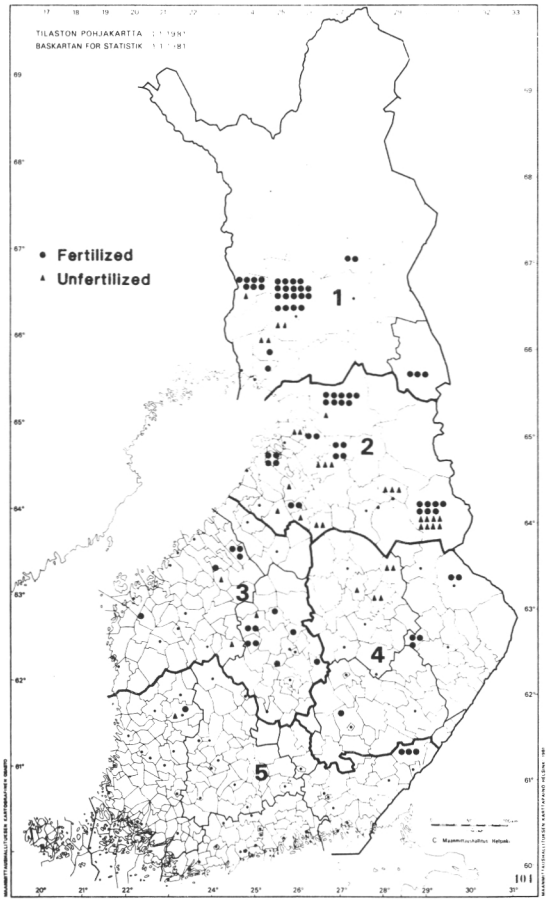


Figure 2. Regional distribution of sample plots with growth disturbance symptoms. Only the shaded areas in Fig. 1 were inventoried (See Fig. 1 for comparision).

southernmost part of the country (area 5) the proportion is very small, about 4 % of all the growth disturbance cases (Fig. 2, Table 3), conforming to the results by Veijalainen (1978). It can also be noted from Fig. 2 that the more frequent occurrence of, especially, unfertilized growth disturbances is largely limited to the northern side of the border between ombrotrophic raised bogs and aapa mire complexes (see Ruuhijärvi 1982, Fig. 1). A reason for the greater frequency of growth disturbances in northern Finland (in the zone of aapa mires) is not known, but may be attributed to the more unfavourable ratio of boron and copper concentrations to concentrations of macronutrients in needles from northern areas as presented by Silfverberg (1980). This also implies a greater risk of inducing growth disturbances when using fertilizers on drained peatlands in northern Finland (Silfverberg 1980). The more adverse climatic conditions in the North probably act together with the nutritional factors in causing growth disturbances.

The dominant tree species in sample plots with disturbance symptoms was pine in more than 95 % of the case; only occasionally spruce or birch *(Betula pubescens)*. The sample plots had in most cases (63 %) a seedling or sampling stand (development class 1) or a slightly more mature stand of class 2. Stands with more mature development classes occurred only sporadically and the basal areas and mean heights of the

stands were thus relatively small.

The occurrence of growth disturbances is concentrated in northern Finland (Areas 1 and 2 in Fig. 1, Fig. 2), where symptoms are found in 3.7 % of drained peatlands; this means an estimated total area of ca. 75 000 ha. With the present results, however, conclusions of the importance on stand productivity of the phenomenon are not possible because the proportion of trees in the sample plots suffering from disturbances was not recorded. Neither is it generally known accurately enough, how severely growth disturbances diminish the productivity of a tree stand. It is, however, possible to conclude that fertilization of the young tree stands in drained, originally treeless peatlands and especially in the group of sedge pine mires in northern parts of the country may significantly increase the risk for occurrence of growth disturbances and thus hamper the profitability of fertilization results.

References

HEIKURAINEN, L. 1982. Ojitusalueiden taimistojen kehityksestä vuosina 1964—68 toimeenpannun suometsäkilpailun koealojen valossa. Summary: Development of seedling stands on drained peatlands. Silva Fenn. 16(3):287—321.

— & PAKARINEN, P. 1982. Mire vegetation and site types. In: Laine, J. (Ed.) Peatlands and their utilization in Finland. Finnish Peatland Society & the Finnish National Committee of the IPS. Helsinki, p. 14—23.

HUIKARI, O. 1974. Hivenravinteet ja puiden kasvu. Metsä ja Puu 11:24—25.

RAITIO, H. & RANTALA, E-M. 1977. Männyn kasvuhäiriön makro- ja mikroskooppisia oireita. Oireiden kuvaus ja tulkinta. Summary: Macroscopic and microscopic symptoms of a growth disturbance in Scots pine. Description and interpretation. Commun. Inst. For. Fenn. 91(1):1—32.

RUUHIJÄRVI, R. 1982. Mire complex types in Finland. In: Laine, J. (Ed.) Peatlands and their utilization in Finland. Finnish Peatland Society & the Finnish National Committee of the IPS. Helsinki, p. 24—28.

SILFVERBERG, K. 1980. Kuusen kasvuhäiriö ja hivenravinteet: Abstract: Micronutritional growth disorder in Norway spruce. Folia For. 432:1—13.

VEIJALAINEN, H. 1975. Kasvuhäiriöistä ja niiden syistä metsäojitusalueilla. Summary: Dieback and fertilization on drained peatlands. Suo 26(5):87—92.

— 1977. Use of needle analysis for diagnosing micronutrient deficiencies of Scots pine on drained peatlands. Seloste: Neulasanalyysi männyn mikroravinnetilanteen määrityksessä turvemailla. Commun. Inst. For. Fenn. 92(4):1—32.

— 1978. Metsäpuiden latvakadon esiintymisestä Suomessa. Summary: Occurrence of die-back of forest trees in Finland. Metsäntutkimuslaitoksen suontutkimusosaston tiedonantoja 1., 22 p.

Total of 9 references

MICROFUNGI AND GROWTH DISTURBANCES IN CONIFERS IN THE ESTONIAN SSR

Märt Hanso

Both forest fertilization and fungal diseases of forest trees are studied in the Estonian SSR. The comprehensive problem "Growth disturbances of forest trees", which unites different sections of the present workshop, has not yet been posed in the Estonian SSR. The Finnish silviculturists, however, have obtained outstanding advances in the solution of the above-mentioned item.

The headings of the majority of reports make such an impression that growth disturbances are discussed in the etiological meaning of being confined to the anomalous nutritional physiology of forest trees. However, a generally accepted standpoint is also the role of infectional factors, primarily that of pathogenic micro-organisms in the formation of growth disturbances in plants. In this case growth disturbances are considered as disease symptoms. The growth disturbances, even in cases of relatively clear etiology, are related to the occurrence of numerous micro-organisms, differing greatly in the degree of pathogenicity. This circumstance aggravates the unique solution of the problem of causal agents.

In the forest pathological situation of the last few years the problem of growth disturbances has become very acute in the

Baltic republics of the Soviet Union, including the Estonian SSR (Hanso 1982). Since growth disturbances are recorded on conifers in forest site types which greatly differ with regard to nutritional and humidity conditions, there remain few possibilities for the study of their causal association with anomalous nutritional physiology.

In the course of forest pathological research in Estonian forests the author has collected both pathogenic and saprothrophic fungi from 1963 onward (Hanso 1978). In addition, starting from 1971 microfungi have been regularly isolated for studies *in vitro*, especially from coniferous plants in forest nurseries. With the aim of diagnosing the damages induced, in the last four years microbiological studies have increasingly been carried out also in middle-aged and old stands where occurrences of growth disturbances have been observed. Herbarium samples (over 10 000 envelopes) are preserved in the herbarium of the Division of forest protection of the Estonian Forest Research Institute as well as in pure culture collection cultures (about 2,500 isolates) are held. This material makes it possible to obtain a review of the species composition of microfungi in shoots and needles of the trees as well as an account of the alteration of the species over a relatively long period.

A more detailed analysis of the respective phenomenon is of secondary importance, considering the topics of the present workshop and it will not be treated here.

Below we shall discuss the occurrence of only one species which has been most frequently associated with growth disturbances, namely *Gremmeniella abietina* (Lagerb.) Morelet (syn. *Scleroderris lagerbergii* Gremm.). This species is known as a pathogen of shoot canker in a number of countries of the temperature zone of the Northern Hemisphere, including Finland (Kurkela, 1980) and Sweden (Barklund and Rowe, 1981).

In the Estonian SSR the fungus has been known since its previous outbreak in 1964...1965 (Hanso 1969, 1973). That outbreak, however, was considerably weaker than the most recent one, the results of which are visible up to the present time (Hanso 1982). In the interval between the outbreaks the disease occurred rarely. In the forest nurseries of the Estonian SSR it accounted only 9,2 % of the total number of the disease incidents in 1969...1971 (Hanso 1974). After that the fungus was not recorded for 6 years. Starting with 1977 shoot canker was again observed in the Estonian SSR. The disease began to be diagnosed on exotic pine species in parks, then also on the Scots pine in forest nurseries. In 1979 and 1980 massive occurrence of the fungus was recorded in pine forests on natural regeneration, and on stunted trees. In 1980 growth disturbances became more frequent. In 1980 and 1981 a massive occurrence of damages was observed also in forest nurseries (Hanso 1982). In addition to pine species, growth disturbances have been observed on the juniper (*Juniperus communis* L.), to a smaller degree also on Norway spruce.

In connection with the occurrence of growth disturbances in conifers in the Estonian SSR, besides *G. abietina*, the species *Aureobasidium pullulans* (deBary) Arn. has been isolated most frequently. The latter is taxonomically close to *Sclerophoma pithyophila* (Corda) Höhn., which according to H. Jahnel and B. Junghans (1957) caused serious damage to pine stands in the German Democratic Republic.

Literature

BARKLUND, P. & ROWE, J. 1981. *Gremmeniella abietina (Schleroderris lagerbergii)*, a primary parasite in a Norway spruce dieback. Eur. J.For.Path. 11(1—2):97—108.

JAHNEL, H. & JUNGHANS, B. 1957. Über eine wenig bekannte Kiefernkrankheit *(Sclerophoma pithyophila)*. Forstwiss. Zbl. 76:129—132.

HANSO, M. 1969. Okaspuu-krumenuloos uus seenhaigus Eestis. In: LUS Aastaraamat (Tallinn) 59:135—139.

— 1973. A brief outline of the research work done in Estonia on the fungus *Scleroderris lagerbergii* Gremmen. In: Proc. I Session Working Party Canker Diseases (*Scleroderris*), Subgroup S2-06, I.U.F.R.O., Minneapolis, U.S.A., p. 8—9.

— 1974. Okaspuuseemikute talvitumishaiguste liigiline koosseis ja levik Eesti NSV metsataimlates aastatel 1969—1971. In: Metsanduslikud uurimused (Tallinn) 11: 259—296.

— 1978. Some materials to the mycoflora of conifers in Estonia. I. *Discomycetes.* Folia Cryptogamica Estonica 10:1—5.

— 1982. Epifitotios Pabaltijo pusynuose. Girionis (Vilnius) 4:12.

KURKELA, T. 1980. Männynversosyöpä ja metsänviljely. Metsänviljelyn koeaseman tied.ant. 35: 33—41.

Total of 8 references

TRACE ELEMENT PROBLEMS INDUCED BY HEAVY NITROGEN FERTILIZATION OF *PINUS RADIATA* IN SOUTH AUSTRALIA

Richard V. Woods

Introduction

The South East Region of South Australia is the only substantial area in the State with adequate rainfall (700—800 mm) for plantation forestry and there is only one major species planted, viz. *P. radiata* (D. Don). The soils are mostly aeolian pod-solised quartz sands of low to very low natural fertility, (Stephens et al. 1941). In the better sandy soils the *P. radiata* plantations have been, in general, remarkably successful with mean annual production rates of 18 to 28 m^3/ha for a rotation of 50 years, but the stands on the deep leached sands and poorly drained heath soils were not successful.

The first nutrient deficiency affecting *P. radiata* in the region was found in the early 1940's to be due to zinc deficiency which caused malformations of the stem resulting from death of the leader in the early years after planting. It was cured by manually spraying zinc sulphate solution to the trees at 2—3 years of age in broad scale operations (Stoate 1950, Adams 1946)

In the early 1950's considerable work with superphosphate on the poorly drained heath soils produced outstanding responses but the well drained upland aeolian sands comprising the bulk of the available area did not respond in like manner. (Boardman 1974). Then in the early 1960's Ruiter (1971) tested combinations of nutrients in factorial trials on these deep white sands. He found that the trees *did* respond to phosphate provided competition was rigidly controlled, but when nitrogen was applied as urea growth disorders appeared unexpectedly six to nine months after treatment. Foliar analysis showed that the abnormal trees were low in copper and zinc viz. less than 2 p.p.m. and 10 p.p.m. respectively. He concluded that the deficiencies were caused by an unbalanced supply of nutrients under otherwise favourable growing conditions.

The general picture in the early 1970's then was that Zn was applied on all plantation at age 2—3 years, phosphate was applied on the wet heath and well drained sands, but nitrogen was not in general use on any of the soil types, despite the fact that nitrogen levels in the upland range soils were low i.e. ca. .05 % (0—20 cm). However, Ruiter (1964) had shown that there was a direct relation between total N and P in the top 0—60 cm of the soil profile and the site productivity on these well drained upland soils. The implication from this work was that trees on those soils *should* respond to the application of both N and P. Despite this, various trials with N in older stands had not produced promising results (Boardman 1974).

Experimental trial RT 20

This leader trial was located in a plantation on Tantanoola Forest (1962 Planting Cpt. 4) for which a superphosphate treatment had been prescribed following foliar sampling at 10 years of age. P levels had been shown to be below adequate (.14 % in South Australia, Raupach and Clarke 1969).

It was the writer's opinion that this stand *should* respond to nitrogen as similar stands, even after P application, remained yellow green and thin in the crown. Consequently a heavy rate of N was applied over the P (100 kg P/ha) dressing viz. 400 kg N/ha as ammonium sulphate in February, 1974 when

Table 1. RT 20 *P. radiata* foliage sampling (Ruiter — pers. comm.). Chemical analysis 1st year needles only. Month of sampling July, 1976.

Treatment	Foliage data O.D.W.			N%	P%	K%	Mg%	Ca%	Mn p.p.m.	Fe p.p.m.	Zn p.p.m.	Cu p.p.m.
	Total on tree (mean B.A. tree)	Fascicle length mm	Fascicle weight mg									
Control	—	122	101	1.12	.066	.88	.18	.26	130	86	13.1	2.4
P100	4.08	127	100	1.30	.163	.80	.21	.41	235	102	14.2	2.5
N400+ P100	6.59	144	121	1.73	.135	.93	.16	.32	205	65	10.6	1.0
Gain % due to adding N over P only	61.5	11.8	21	33	—20.7	16.2	—24	—22	—14.6	—36	—34	—60
Deficient levels less than				1.5	.13	.4	.1	.1	20—30?	30—40?	10—12	2—3

the trees were 12 years of age. Four paired plots were located for mensuration purposes on the N + P strip and the adjoining P only area.

The response to the N application was dramatic in the spring (September) of 1974. Foliage density and colour had therefore improved markedly within 7—8 months from treatment. However, in the spring of 1975 serious distortion occurred in the upper branches and leaders of some of the N + P trees. In addition there was serious needle cast of the 3 year old foliage in the N + P treatment. No physiological problems were evident in the P treatment.

Foliar samplings were taken in July, 1976 (Ruiter, pers. comm.) and the results are shown in Table 1. In addition one tree of mean basal area in each treatment was felled and the total foliage weighed to give rough O.D.W. foliage comparisons. Table 1 shows that there was a large increase after adding N to P only in total foliage weight (61.5 % increase) and a lesser increase in mean needle weight (21 %). Nitrogen levels increased 33 % from below to above adequate, but phosphorous dropped 20.7 % to near marginal levels, apparently due to dilution effects. Potassium was lifted 16.2 % despite no K being applied. Zinc levels dropped 34 % and Cu dropped 60 %. Both the Zn and Cu levels in the N + P trees were near or below critical levels (10—12 p.p.m. and 2—3 p.p.m. respectively). Mn and Fe levels dropped 14.6 and 36 % respectively but were still well above critical levels. Thus although Mn, Fe, Zn and Cu foliar levels all weakened as a result of the dilution effect following the response to N + P, only Zn and Cu fell below adequate levels. Cu dropped to a critical value of 1 p.p.m.

In 1978 the 4 replications of paired plots were measured for basal area increment over the 3 year period 1975—1977 with the following results:

Plot Pair No.	Treatment	Initial S.Q.	3 year Inc. B.A. m^2/ha	Gain due to N B.A. m^2/ha	% gain
4	P	V/VI	7.82	—	—
	N+P	V/VI	10.28	2.46	31.5
2	P	VI	8.49	—	—
	N+P	VI	11.18	2.69	31.7
1	P	VI/VII	8.23	—	—
	N+P	VI/VII	11.57	3.34	40.6
3	P	VII	7.53	—	—
	N+P	VII	11.08	3.55	47.1

It is clear there was a good gain in B.A. to the addition of N, inversely related to site class. This greater response in lower site classes to fertilizer N is typical of the pattern recorded in U.S.A. (Miller and Fight 1979) and Sweden (Möller and Petterson 1980).

In late 1980, stem analyses were made on two predominant trees from each of the N + P and P treatments located near plot pair No. 4. Figure 1 shows that the P only treatment did not affect height increment compared with 'normal' height increment

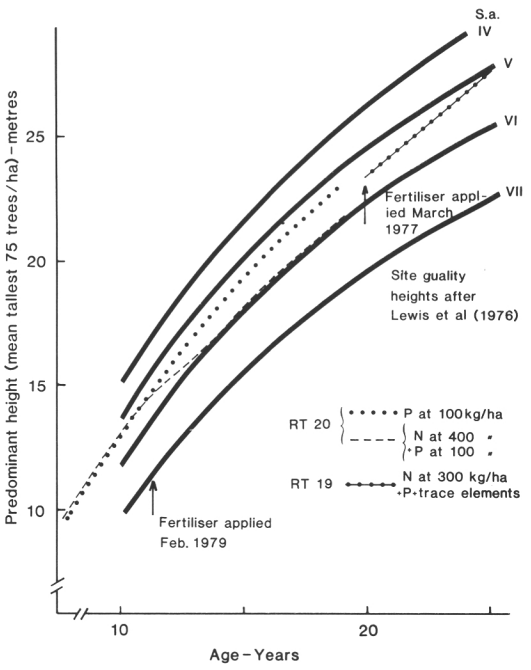


Figure 1. Height trends after additions of fertilizer. Means of two predominant trees/treatment. Tantanoola F.R. 1962 Ptn. Cpt. A.

(Lewis et al. 1976) but that the N + P treatment depressed height increment for about 3 years after treatment. Subsequently these trees have recovered near normal height increment close to the S.Q. VI growth curve.

Figure 1 also shows the height trends of a plot (RT 19) on a similar soil type in an adjoining block which was treated in 1977 with 300 kg N/ha in a mixture with P and trace elements (including Zn and Cu) at age 20 years. In this case there is a distinct *gain* in predominant height increment in the 5 years since treatment. There was no distortion of the tops or needle cast in this trial following treatment.

Discussion

Foliar sampling after treatment with high N application shows that the distortion of the leaders and the subsequent loss of height increment for a period in RT20 was the result of Cu dilution following the growth flush from added N. The Cu levels were critical (1 p.p.m.) in the high N + P plots. Will (1978), Stone (1968) and Baule and Fricker (1970) all describe distortion of branches and leaders as the result of Cu deficiency in forests. It is accentuated by fertilizer N application, or even deep ploughing of organic soils leading to a flush of mineralised N. The recovery of height increment after 3 years in RT20 would suggest that Cu levels had improved to above critical levels, but no later foliar analyses have been done to confirm this. As B.A. increment was markedly improved when N + P was applied compared to P only, but height increment was depressed, it is clear that the form of the N + P trees must have been quite drastically changed by the treatment.

In contrast when trace elements including Zn and Cu were applied to an N + P mixture in RT19 on a similar soil type there was an actual gain in height increment, no distortion of the leaders, and no needle cast. The gain in basal area for 3 years after treatment with 300 kg N/ha and associated elements was 71.4 % over controls. Table 1 shows that in RT20 Zn and Cu were the only trace elements to drop below adequate levels when N + P was applied, i.e., that Mn and Fe were not limiting even when not applied and *despite* some dilution effects. The inference from this work is that the gain in height and B.A. increment when N + P and a mixture of trace element was applied in RT19 is the result of the Zn and Cu added in the mixture.

These trials do not separate the differential effects of Cu or Zn and hence no statement can be made whether they are acting independently, interacting with one another, or interacting with the major elements N and P added simultaneously in the fertilizer mixture.

These trials together with over confirmatory trials in the Region have resulted in a policy of using a balanced mixture when treating similar unhealthy stands on the deeper sandy soils in the Region. The formula is known as Forest Mix No. 4 and it contains 12.8 % N as ammonium sulphate, 2.2 % P as superphosphate, 19.4 % S, .8 % Cu, .75 % Zn, and .002 % Mo. The standard application rate at mid rotation is 1.45 t/ha of this mixture which supplies 200 kg N/ha together with P, Zn, Cu and Mo in the ratios as indicated in the formula.

In the five years since this formula was developed for the South East Region ca. 15 000 tonnes of this mixture have been applied to unhealthy stands ranging from S.Q. VII up to V. Good responses have been universal with gains in volume increment of the order of 8 to 15 m^3/ha/annum for at least 3 to 4 years after treatment. There have been no growth disturbances as a result of this work and universal gains in height increment. Figure 2 illustrates these gains in height increment in the trials RT33 Series at Penola Forest. This series has 5 to 6 replications in all control and treated plots. Figure 2 shows quite clearly that the greater gains in height increment are obtained on the lower site qualities, similar in principle to the B.A. gains in RT 20.

Although the responses to the five element mixture in South Australia have been very pleasing, much more work is needed to separate out the benefits and interactions of the five elements concerned. This could only be done in complex factorial trials.

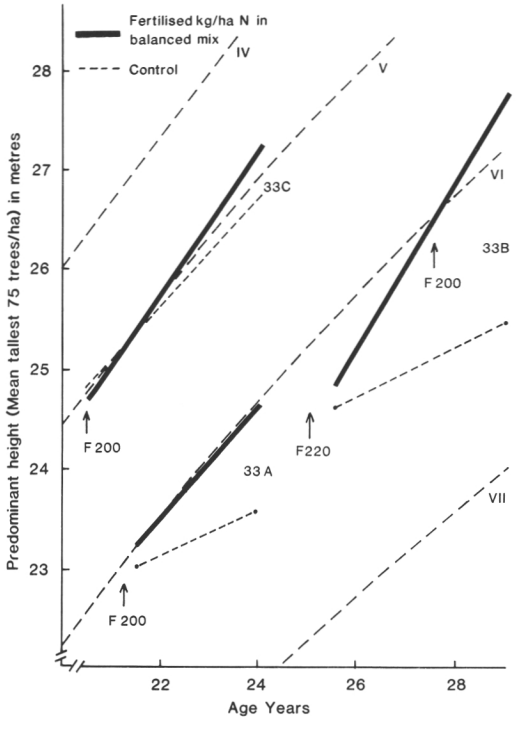


Figure 2. Height responses to post thinning fertilizing. RT 33 series — Penola F.R.

Woods (1976) has shown in trials on young plantations on similar soils in the Region that, even when Cu is included in the N + P etc., mixture, distortion can be induced if the dose rate of N is high relative to the biomass of the tree. The problem did not occur when the dose rate was halved. Simpson (pers. comm.) working with *P. caribea* in Queensland has shown severe distortion and even total collapse in young trees following additions of N + P on poor coastal sands. Annual foliar copper sprays have corrected the problem.

It would appear that this problem is governed by the relation between dose rate of N and biomass, and relative Cu immobility in the tree and/or poor root uptake of Cu from the soil. The added N is readily taken up by the tree and moves to the new shoots producing a large flush of growth but without comparable root uptake or similar rate of Cu mobility in the tree. The imbalance of Cu to N in the young shoots leads to the distortion and loss of height increment. Indirect evidence suggests that potential volume increment is lost when Cu is not added to N + P mixtures on sandy soils in the Region. In addition growth disturbances can occur, even with Cu in the mixture, if N + P application rates are too high relative to the biomass of the trees.

References

ADAMS, A.J.S. 1946. Zinc in the South Eastern Forests of South Australia. Aust. Timber Journal 12.

BAULE, H. & FRICKER, C. 1970. The fertilizer treatment of forest trees. BLV Verlagsgesellschaft MbH, Munchen.

BOARDMAN, R. 1974. Pine Stand Improvement in the South Eastern Region of South Australia. Woods & Forests Dept., Bulletin 21.

LEWIS, N.B., KEEVES, A. & LEECH, J.W. 1976. Woods & Forest Dept., South Australia, Bulletin 23, 147 p.

MILLER, R.E. & FIGHT, R.D. 1979., Fertilizing Douglas Fir Forests. General Tech. Re. PNW — 83 U.S.D.A.

MÖLLER, G. & PETTERSON, F. 1980. Gödsling (79—80) NR2 Institut för Skogsförbättring, Uppsala, Sweden.

RAUPACH, M.R. & CLARKE, A.R. 1969. Soil Publication 26 — C.S.I.R.O.

RUITER, J.H. 1964. The water relations of *Pinus radiata* (D. Don) in the lower South East of South Australia. M.Sc. Thesis, University of Adelaide.

RUITER, J.H. 1971. The importance of trace elements in the establishment in the deep white sands of the

South-East of South Australia. In: Boardman. R. (Ed.). Aust. Forest-Tree Nutr. Conf. Sept. 1971. Canberra. A.C.T. Forestry & Timber Bureau, p. 164—167.
STEPHENS, C.G. et al. (1941). A soil and land use survey of five hundreds, County Grey, South Australia. C.S.I.R.O. Bulletin 142.
STOATE, T.N. 1950. Nutrition of the Pine. Bulletin 30, Forestry & Timber Bureau, Canberra.
STONE, E.L. 1968. Microelement nutrition of forest trees: A review. In: Forest fertilization — theory and practice. Symp. For. Fert. April. 1967. Knoxville, USA. Tennesee Valley Authority. Muscle Schoals, Ala., p. 132—175.
WILL, G.M. 1978. New Zealand Journal For. Sc. 8(1).
WOODS, R.V. 1976. Early Silviculture for upgrading productivity on marginal *Pinus radiata* sites in the South Eastern Region of South Australia. Woods & Forests Department, Bulletin No. 24.

Total of 14 references

ESTABLISHMENT OF *PINUS RADIATA* ON CALCAREOUS SOILS

John H. Ruiter

Manganese deficiency in radiata pine on moist alkaline humic sands and on dry hill-top rendzinas in south-eastern South Australia and south-western Victoria has been confirmed. Recovery from deficiency was rapid following foliage applications of manganese sulphate, but was slower with soil applications. In both cases retreatment was required within two years of initial application. Superphosphate appeared beneficial, but manganese sulphate was necessary to maintain health. The critical concentration of manganese in the foliage is discussed in relation to visual symptoms. Where from visual symptoms manganese deficiency was suspected at establishment, but no response was obtained from manganese sulphate, iron proved to be deficient in young, developing foliage and trees responded to iron sulphate. The results suggest that iron is primarily deficient in the establishment phase of *Pinus radiata* (D. Don) on calcareous soils, and that manganese may be deficient at establishment but is primarily deficient in established trees.

Introduction

Calcareous and heavily limed soils are notorious for producing lime-induced chlorosis and nutrient deficiencies such as phosphorus, iron, manganese, zinc, and copper in a variety of crops. In the alkaline environment the availability of these elements is reduced through excess bicarbonate or by chemical and biological fixation. Lime-induced chlorosis has for similar reasons attracted increasing attention in nursery and forest management of conifers during the last three decades (Dale et al. 1955; Ingestad 1958; Themlitz 1958; Wehrmann 1964; Laatsch 1967; Zech 1969, 1970a, 1970b; Kreutzer 1970; Nelson and Selby 1974; Le Tacon 1974, 1978; Nakos 1975, 1979; Clement 1977; Carter 1980, 1981).

Although calcareous soils occupy only small areas in the plantations of radiata pine in south-western Victoria and south-eastern South Australia they can be relatively large in some compartments, producing failure, chlorosis and stunted tree growth. Foliage analysis of affected trees suggested manganese deficiency ($<10\mu g \cdot g^{-1}$ Mn, Lange 1969), so that experiments were conducted to confirm this, and to examine ways of using manganese fertilizers to overcome the disorder. However, establishment problems remained, which on further investigation revealed the existence of iron deficiency. Zinc and copper deficiencies are also reported.

Experimental Methods

In Experiment I were investigated the manganese, zinc and copper requirements of pines planted on an alkaline sand (pH 8), typical of locally restricted swampy depressions, where the previous crop had shown very low foliage concentrations of these elements. Seedlings were planted in winter (August) 1982 and three weeks later fertilizer was added in pockets 0.10 m to 0.15 m from each seedling. Treatments, applied to single-row plots of eight trees, and replicated three times in a randomized block design, were:

— 170 g superphosphate per tree (P),
— P + 40 g manganese sulphate per tree (PM),
— PM + 20 g zinc sulphate per tree (PMZ),
— PMZ + 40 g copper sulphate per tree (PMZC).

Four half-sib families of radiata pine (50030, 50043, 50047, 50080) were used, each being randomly represented by two trees in each row. Weeds entering in autumn 1973 were controlled by atrazine. Because visual symptoms of manganese deficiency showed in manganese-treated trees in the spring of 1973, these trees were given a foliage spray of 40 ml (3.5 g Mn) of a fifty per cent aqueous solution of manganese sulphate.

Experiment II was established to investigate suspected manganese deficiency in three-year-old pine on Bridgewater Sandy Loam (Gibbons and Downes 1964), a calcareous hill-top rendzina of pH 8, characteristic of coastal south-western Victoria. The pines showed retarded growth of varying intensity and an equally varied yellowing of the foliage, often severely necrotic from the tip downwards, and with manganese concentrations of 3 to 10 $\mu g \cdot g^{-1}$. They had been sprayed twice with zinc sulphate, unsuccessfully. Unit plots of single or double rows of six uniform trees were replicated four times in a randomized block design, and treated in spring (September) 1973 with:

(a) Nil treatment;
(b) 20 ml foliage spray per tree of a fifty per cent aqueous solution of commercial manganese sulphate (1.7 g Mn);
(c) 40 ml foliage spray per tree as for (b), (3.5 g Mn).

An earlier attempt to establish radiata pine on a hill-top rendzina with the help of a soil application of manganese sulphate had proved inconclusive, the one-year-old trees being deficient in phosphorus, low in nitrogen and potassium, and high in calcium. To examine this problem Experiment III was established on the same soil type, using acidic fertilizers, applied to the soil with and without manganese sulphate, at time of planting. Treatments included:

(a) Nil treatment (O);
(b) 80 g of ammonium sulphate (21 % N), (A);
(c) 80 g of superphosphate (8.6 % P), (P);
(d) 80 g of elemental sulphur (90 % S), (S);
(e) 80 g of manganese sulphate (28 % Mn), (M);
(f) (b) + (e), (AM);
(g) (c) + (e), (PM);
(h) (d) + (e), (SM);
(i) (e) + complete mineral mixture (Woods 1976) (7.0 % N, 3.9 % P, 3.3 % K, 0.40 % Mn), (CM).

One-year-old seedlings of three halb-sib families (50043, 50048, 50178) and a random seed mixture were randomized in 16-tree plots, and planted in a randomized block design with eight replications in winter (August) 1976. The fertilizer was applied six weeks later in two slits 0.10 m deep, on opposite sides and 0.10 to 0.15 from each tree. The total experimental area was then sprayed with amitrol/atrazine herbicide and again the following autumn and subsequent mid-summer, mowing being carried out when necessary.

Foliage analysis. This was used at yearly intervals as a diagnostic tool, and no monitor response in the various experiments.

(1) In an unpublished experiment, both six-year-old untreated trees and those treated four years earlier with a soil application of superphosphate and manganese sulphate generally showed reasonable colour and growth, despite foliage manganese concentration less than 10 $\mu g \cdot g^{-1}$. To examine this, foliage samples were taken from a tree obviously deficient in manganese, but with green sections in the foliage, and from a healthy tree, but showing slight yellowing in the foliage. The samples were obtained from the leading shoot, the top whorl, and the next two lower spring whorls with two and three ages of foliage, respectively. About ten fascicles from each position were partitioned where colour changed, and the manganese content of the sub-samples determined.

(2) The foliage element concentration of both healthy and yellow untreated three-year-old and of 6- to 12-month-old radiata pine was compared. Since the youngest trees showed very low, but not deficient, manganese concentrations the influence of acid washing on foliage element content was examined, as well as the element content of very young developing foliage.

(3) After washing in 1 N hydrochloric acid, the element content was also determined of three ages of foliage along a one-year-old branch from each of three one-year-old trees, which showed a healthy green colour and good growth in the first growth season, but vigorous though yellow new shoots.

Measurements and Analyses

Tree heights and diameters at 0.15 m and 1.30 m were measured annually. Samples of mature-sized, 0.5- to 1-year-old foliage from the topmost whorl were collected in June, fascicle length and weight measured, and samples dried at 70 °C for 24 hours, ground and analysed (Lowther 1980). Where only manganese content was required samples were incubated in 10 % v/v HCl at 70 °C for 24 hours, and the solution assayed for total manganese by atomic absorption. Comparison with sulphuric acid/hydrogen peroxide digests, showed that all manganese was extracted from the samples. For critical determination of iron content the foliage was washed in a 1 N solution of hydrochloric acid for two minutes followed by five rinsings with deionised water. General observations on foliage colour and deficiency symptoms were also made annually. Munsell Color Charts (Munsell Color Company 1952) were used for detailed colour comparisons.

Results

Experiment I. Since there was no statistically significant difference between families all data were pooled. The results in Table 1 show that, despite their healthy appearance, all trees grew slower than expected in the first season, regardless of treatment. In terms of manganese uptake, the one-year-old treated trees had responded well, since the controls showed manganese concentrations of 13 to 20 $\mu g \cdot g^{-1}$ and the treated rows concentrations of 77 to 288 $\mu g \cdot g^{-1}$. Nevertheless, a few months later new shoots of treated trees became severely chlorotic, which was alleviated by an immediate foliage spray of manganese sulphate applied to all treated trees. By the completion of the second growth season diameter growth had responded to treatment, and subsequently the difference between the control and manganese treatments continued to increase in significance. However, height increment showed a significant difference in the third and fourth seasons only. Deficiency symptoms of manganese, zinc and copper were clearly present at age seven years, regardless of treatment. Zinc deficiency was evenly distributed over the area, but the deficiencies of manganese and copper were localised, and rarely occurred in the same trees.

Table 1. Experiment I. Tree heights and diameters of trees planted in 1972 on an alkaline humic sand and treated with (P) superphosphate, (PM) P plus manganese sulphate, (PMZ) PM plus zinc sulphate, (PMZC) PMZ plus copper sulphate

Treatment	1972	1973	1974	1975	1976	1977*
	Year					
	Age (y)					
	0	1	2	3	4	5
	Height (m)					
P	0.27	0.50	1.24	2.05	3.67	6.08
PM	0.26	0.54	1.38	2.63[a]	5.01[a]	7.42
PMZ	0.26	0.55	1.39	2.58[a]	4.79[a]	7.15
PMZC	0.27	0.50	1.24	2.33	4.52	6.93
LSD (P<0.05)	0.03	0.06	0.26	0.42	0.79	0.98†
	Diameter 0.15 m (mm)				Diameter 1.30 m (mm)	
P	5	11 29	52	82	53	89
PM	6	12 38[a]	73[a]	119[b]	85[b]	128[c]
PMZ	5	13 39[a]	76[a]	120[b]	85[b]	128[c]
PMZC	5	12 34	70[a]	112[b]	80[b]	126[c]
LSD (P<0.05)	1	2 7	13	15	16	13

[a] Significantly different from the control (P) at $P < 0.05$.
[b] Significantly different from the control (P) at $P < 0.01$.
[c] Significantly different from the control (P) at $P < 0.001$.
* The 1977 measurements were made in August, two months later than in previous years, thereby exaggerating the increments for 1976/77, especially those of height (by about 0.5 m).
† Since the F ratio was not significant no significance is indicated.

Table 2. Experiment II. Tree heights and diameters of trees which received a foliage application of manganese sulphate at two rates at age three years (1973) compared with untreated control trees

Treatment	Sep. 1973	June 1974	June 1975
	Height (m)		
Nil treatment	1.09	1.35	1.68
10 ml manganese sulphate (1.7 g Mn)	0.94	1.33	2.26[b]
20 ml manganese sulphate (3.5 g Mn)	1.09	1.54	2.69[b]
LSD ($P < 0.05$)	0.27	0.28	0.41
	Diameter 0.15 m (mm)		
Nil treatment	29	36	43
10 ml manganese sulphate (1.7 g Mn)	23	37	60[a]
20 ml manganese sulphate (3.5 g Mn)	25	41	67[a]
LSD ($P < 0.05$)	9	11	14

[a] Significantly different from the control at $P < 0.05$.
[b] Significantly different from the control at $P < 0.01$.

Experiment II. Four-and-a-half months after treatment, foliage colour of the upper crown had almost completely changed from yellow to dark green in all treated trees, and this change was complete after nine months. It was associated with a rise in foliage manganese concentration to approximately 40 $\mu g \cdot g^{-1}$. The foliage had gained in weight but not in length. Height and diameter increment showed a significant difference ($P < 0.01$) between treated and untreated trees in the first growth season, but total height and diameter not until the second winter after treatment due to large initial variance (Table 2). No significant differences both in manganese concentrations and responses were detected between the manganese treatments. However, by the second year, manganese concentrations in the foliage had dropped to levels of 5 to 11 $\mu g \cdot g^{-1}$, and deficiency symptoms reappeared in the upper crowns.

Experiment III. The first herbicide application caused yellowing and may have contributed to mortalities, but many were attributable to ammonium sulphate ($P < 0.001$), with or without manganese sulphate (AM and A) or in complete mineral mixture (CM). Family 50043 was least affected ($P < 0.001$). At three years height and diameter had responded significantly to superphosphate, with and without manganese sulphate (PM and P), whilst diameter had responded just significantly to manganese sulphate (Table 3). Complete mineral mixture plus manganese sulphate (CM), containing ammonium sulphate, was not included in the analysis, but height and diameter were very similar to those for

Table 3. Experiment III. Summary of mensuration data at age three years from planting, including the effects of acidifiers, manganese and families

Acidifier	Nil	Ammonium sulphate	Sulphur	Super-phosphate	LSD	Significance
Height (m)	1.05	0.82	1.00	1.18	0.10	P<0.001
Diameter 0.15 m (mm)	29	21	27	32	3	P<0.001

Manganese	Nil	Applied	LSD	Significance
Height (m)	0.99	1.04	0.07	N.S.
Diameter 0.15 m (mm)	26	28	2	P<0.05

Family	50043	50048	50178	Mixture	LSD	Significance
Height (m)	1.10	1.03	0.94	0.98	0.08	p<0.01
Diameter	30	27	26	26	3	p<0.01

ammonium sulphate. Family 50043 performed better in both height and diameter (P<0.01) than 50048 and 50178, or the mixture. One year later a survey showed that, overall, manganese sulphate contributed significantly to the health of the trees (P<0.001), and that both superphosphate and sulphur added substantially to the effect (Table 4).

Table 4. Experiment III. The effect of manganese fertilizer at planting on tree health at age four years. The figures represent the average number of healthy trees per plot expressed as a percentage of live trees (LSD 20, P < 0.05). The figures in brackets include healthy trees as well as those with slight deficiency symptoms (LSD 21, P < 0.05)

Acidifier	Manganese	
	Nil	Applied
Nil	16 (41)	32 (60)
Ammonium sulphate	14 (34)	28 (63)
Sulphur	18 (45)	51 (83)
Superphosphate	31 (63)	55 (91)
Complete mineral mixture	— —	47 (81)

Where in Experiments I to III and those unreported, tree height and diameter increments; and foliage dimensions, increased in response to manganese fertilizer, they decreased with a return to deficiency, until under severe conditions the trees showed the stunted growth and chlorotic, sparse foliage described by Lange (1969). Foliage length showed a high correlation ($r = 0.90$, $n = 96$) with height increment of the same season, suggesting that both reacted to a similar degree to prevailing growth conditions.

The expression of manganese deficiency symptoms in established trees varied considerably. Generally, they were greater in the lower part of the tree and less towards the top, but not infrequently one or two branches below the top whorl appeared most affected. The leading shoot and top whorl were generally least affected or showed no symptoms, though again striking exceptions were observed (Experiment I). In chronic cases the tops died first, and yellow to yellow-green current year's foliage was present only on the lowest branches. Variations were also common within the needles themselves; often the apical sections were yellow, at other times the basal sections, the central sections or the whole needles. Colour variations were large, varying from a light green colour, e.g. 7.5 GY 6.5/6 in the Munsell notation, through 5 GY 4/6 to 6/8 and 2.5 GY 6/7 to 7/8 (Lange 1969) to yellow 5.0 Y 7/8 to 8/8 (Marcos de Lanuza 1966). Yellow foliage was often severely necrotic (10 R 4/4 to 5.5/6), extending from the tip downwards.

Foliage analysis

(1) The green and the yellow sections of the foliage of both trees sampled differed in manganese content; green sections (7.5 GY 4/3 to 5/4) had an average concentration of 6.1 $\mu g \cdot g^{-1}$ (99.9 % confidence interval: 5.3 $\mu g \cdot g^{-1}$ to 6.9 $\mu g \cdot g^{-1}$), and the yellow-green sections (5 GY 4/6 to

Table 5. Mean element content (s.e. in brackets) of mature-sized, six- to twelve-month-old foliage of six months to three-year-old trees on hill-top rendzina soil. The summer 1980/81 collection consisted of the tree's complete foliage.

Season:	Autumn 1973				Summer 1980/81		Winter 1981	
Age (y):	3*		1**		0.5†		1††	
Condition:	Healthy	Yellow-green	Healthy	Yellow	Healthy	Yellow	Healthy	Yellow
Sample size (n)	2	2	2	2	6	6	10	10
Nitrogen (%)	1.57 (±0.15)	1.30 (±0.03)	2.02 (±0.01)	1.38 (±0.15)	1.65 (±0.05)	1.68 (±0.05)	2.12 (±0.04)	1.30 (±0.07)
Phosphorus (%)	0.137 (±0.001)	0.127 (±0.004)	0.121 (±0.006)	0.094 (±0.000)	0.106 (±0.006)	0.132 (±0.007)	0.162 (±0.005)	0.113 (±0.007)
Potassium (%)	0.62 (±0.02)	0.65 (±0.09)	0.73 (±0.03)	0.78 (±0.01)	0.86 (±0.03)	0.81 (±0.05)	0.96 (±0.02)	0.88 (±0.06)
Calcium (%)	0.28 (±0.005)	0.24 (±0.01)	0.39 (±0.003)	0.38 (±0.03)	0.29 (±0.02)	1.22 (±0.06)	0.70 (±0.13)	2.27 (±0.11)
Magnesium (%)	0.11 (±0.005)	0.10 (±0.004)	0.09 (±0.03)	0.08 (±0.01)	0.13 (±0.01)	0.19 (±0.01)	0.12 (±0.01)	0.19 (±0.01)
Iron ($\mu g \cdot g^{-1}$)	85 (±13)	68 (±1)	102 (±8)	111 (±23)	303 (±35)	314 (±14)	58 (±2)	202 (±21)
Manganese ($\mu g \cdot g^{-1}$)	15 (±7)	3 (±0)	28 (±1)	63 (±5)	31 (±4)	24 (±1)	16 (±2)	166 (±16)
Zinc ($\mu g \cdot g^{-1}$)	21 (±9)	19 (±2)	5 (±1)	13 (±1)	21 (±1)	25 (±1)	40 (±2)	51 (±4)
Copper ($\mu g \cdot g^{-1}$)	3.0 (±0.1)	3.6 (±0.1)	1.4 (±0.5)	0.9 (±0.2)			5.6 (±0.2)	2.1 (±0.2)
Sodium (%)	0.14 (±0.03)	0.16 (±0.04)	0.08 (±0.01)	0.24 (±0.02)				
Chlorine (%)	0.62 (±0.06)	0.72 (±0.08)	0.49 (±0.01)	0.93 (±0.00)				
Phosphorus/ Iron	16	19	12	8	3.5	4.2	2.8	5.6
Potassium/ Calcium	2.2	2.7	1.9	2.1	3.0	0.7	1.4	0.4

* Samples washed in distilled water. Healthy samples from area adjacent to affected area.
** Samples unwashed. Healthy samples from affected area.
† Samples unwashed. Healthy samples from sandy soil adjacent to affected area.
†† Results of unwashed samples and those washed in deionised water and in 0.05 N HCl were pooled for each tree since there were no significant differences except for iron for which results of the washed samples were used. Healthy samples from sandy soil adjacent to affected area.

5/6) 3.2 $\mu g \cdot g^{-1}$ (99.9 % confidence interval: 2.5 $\mu g \cdot g^{-1}$ to 3.9 $\mu g \cdot g^{-1}$). The results suggest a critical concentration of about 5 $\mu g \cdot g^{-1}$.

(2) The autumn 1973 sampling of three-year-old trees (Table 5) showed normal concentrations of all elements except for very low to deficient values for manganese, and high contents of chlorine, which might have caused the foliage burn in the yellow, manganese deficient, foliage. Spraying with manganese sulphate (Experiment II) overcame the disorder. However, simultaneous sampling of nine-month-old trees on the same soil type (Table 5) showed yellow foliage to be deficient in phosphorus and copper, very low in magnesium and excessive in chlorine, whilst green foliage was very low in magnesium and deficient in zinc and copper. Manganese and iron concentrations were adequate in both cases. Nevertheless, the symptoms resembled manganese deficiency, but not phosphorus, magnesium or copper. A similar situation had developed on a larger scale in six-month-old trees on rendzina in summer 1980/81. The element content of the total foliage (Table 5) could not be faulted except for very high concentrations of calcium and iron, whilst manganese was low but not deficient. Spraying with manganese sulphate in late-summer 1981 raised concentrations in the following winter (Table 5), but failed to correct the disorder.

To avoid surface contamination from the sprayed manganese sulphate the foliage samples were washed in deionised water or 0.05 N hydrochloric acid. Neither affected element concentration, including manganese (sodium and chlorine were not analysed), except for iron, which was significantly reduced by 17 to 27 per

Table 6. Element content of three ages of foliage along a one-year-old branch in three one-year-old trees, September 1981

Element Unit	Age of foliage (months)			LSD (P<0.05)
	8 dg*	4 gy/g*	2 gy*	
Nitrogen (%)	1.47	1.74	2.15	0.22
Phosphorus (%)	0.122	0.203	0.279	0.053
Potassium (%)	0.39	0.86	1.36	0.29
Calcium (%)	2.16	1.15	0.60	0.68
Magnesium (%)	0.18	0.11	0.09	0.05
Iron ($\mu g \cdot g^{-1}$)	76	34	17	15
Manganese ($\mu g \cdot g^{-1}$)	190	36	19	25
Zinc ($\mu g \cdot g^{-1}$)	45	40	37	17
Phosphorus/Iron	16	61	160	44
Potassium/Calcium	0.19	0.75	2.32	0.84
Iron/Zinc	1.83	0.85	0.46	0.65

* Subjective colour description: dg = dark green
gy = greenish yellow
g = green.

cent, whilst 1 N hydrochloric acid reduced this another 34 per cent compared to unwashed samples.

(3) The element content of the three one-year-old trees showing recent yellowing was subjected to analysis of variance (Table 6). The mature-sized dark green eight-month-old foliage, a normal sample for comparison between trees and treatments, contained adequate amounts of nitrogen, magnesium, iron, manganese and zinc, was low in phosphorus, marginal in potassium, and high in calcium. However, with decreasing age (and size) of foliage, nitrogen, phosphorus, and potassium increased sharply, whilst the opposite took place for calcium, magnesium, iron and manganese. As a result the phosphorus/ iron ratio rose sharply from a normal value of 16 for the oldest foliage to 160 for the youngest, whilst the potassium/calcium ratio rose similarly from a very low 0.19 to a more normal value of 2.3. Manganese was low but not deficient in the youngest foliage, whereas iron was very low at 17 and 34 $\mu g \cdot g^{-1}$ for 2- and 4-month-old foliage, respectively.

Discussion

Experiment II clearly confirmed the original diagnosis of manganese deficiency. Foliage application of manganese sulphate resulted in a rapid correction of the disorder, both high and low rates being equally effective. However, the response to soil applications at time of planting was generally delayed and sometimes absent. These results reflect Ingestad's (1958) experiences with Norway spruce, where whatever the mode of application used in the experiments, invariably a second application was necessary within one to three years because of the reappearance of deficiency symptoms.

The visual expression of the deficiency symptoms varied considerably. Foliage samples taken both from a fertilized and an unfertilized tree showed a relatively sharp dividing line between the manganese content of yellow and green sections, suggesting a critical level of 5 $\mu g \cdot g^{-1}$. However, since foliage was rarely found to be entirely chlorotic deficiencies could occur in needles with concentrations higher than 5 $\mu g \cdot g^{-1}$, depending on the amount of manganese in the green sections of the needles. Lange's (1969) suggested critical level of 10 $\mu g \cdot g^{-1}$ therefore still appears to be the best guide for samples containing entire needles.

In Experiment I, III and an unreported experiment involved with the establishment of radiata pine on alkaline soils, superphosphate was invariably associated with the response to manganese sulphate. Although in Experiment I it was added as a blanket treatment at planting, it did not prevent chlorosis from appearing in the second spring, even in the manganese-treated plots. This was alleviated by a foliage application of manganese sulphate. In the unreported experiment there was no response to manganese sulphate until the trees were refertilized in the third spring, this time with the addition of superphosphate. The results could be interpreted as a response to superphosphate, though improvement in foliage colour and manganese concentration also indicated a response to manganese application. The results of Experiment III three years from establishment confirmed a convincing response to superphosphate, with and without manganese. But manganese sulphate improved diameter growth, and a survey at age four years showed that all treatments that had received manganese sulphate at planting were visually in much better health than those that had not. Obviously, superphosphate alone could not maintain tree health.

Despite the responses to manganese sulphate, with and without superphosphate,

establishment of radiata pine on the calcareous rendzina soils was invariably slow. This was often associated with unusually high concentrations of foliage calcium whilst variously nitrogen, phosphorus and/or potassium were low. In addition, six-twelve-month-old trees with symptoms resembling manganese deficiency had satisfactory manganese concentrations, 24 to 63 $\mu g \cdot g^{-1}$. de Lanuza (1966) observed a drop in critical manganese concentration for total seedling foliage from 40 $\mu g \cdot g^{-1}$ at age three months to 12 $\mu g \cdot g^{-1}$ at age nine months. A similar development could perhaps occur in the first twelve months after planting in the field. However, a foliage application with manganese sulphate did not alleviate the problem. It was not until the foliage samples were washed in 1 N hydrochloric acid and younger, immature foliage was analysed that very low concentrations of iron were found (Table 6).

There is little published information on deficiency levels for iron in coniferous species; because unwashed samples are widely used, Stone (1968) considered that no reliable information was available. de Lanuza (1970) suggested a critical range of 35 to 45 $\mu g \cdot g^{-1}$, and deficiency less than 35 $\mu g \cdot g^{-1}$, in foliage of six-month-old radiata seedlings grown in culture solution, values corresponding to a critical range of 25 to 40 $\mu g \cdot g^{-1}$ quoted by Wallihan (1966) for orchard crops. Accordingly, the concentrations of 17 and 34 $\mu g \cdot g^{-1}$ for iron in 2- and 4-month-old yellow green foliage in Table 6 could be regarded as deficient and critical, respectively. The sharply increasing phosphorus/iron and potassium/calcium ratios with decreasing iron concentration also correspond with DeKock's (1964) observation. In addition Watanabe et al. (1965, quoted by Stone 1968), found that on calcareous soils a nutrient balance involving phosphorus, zinc and iron had a strong influence on growth, such that yields decreased as the iron/zinc ratio fell below 1.5. The yellow 4- and 2-month-old foliage in Table 6 also shows ratios less than 1.5. Addition of iron would therefore rectify the balance between iron, phosphorus and zinc. A subsequent commercial foliage application of iron sulphate, as suggested for pea crops in the district (Seeliger and Moss 1976), has largely overcome the yellow, stunted condition of the trees. Where young, immature foliage is absent, the 'active' (or ferrous) iron content of the older foliage may have to be determined to confirm iron deficiency (Zech 1970b; DeKock et al. 1978). Zech (1970b) found a sharply defined critical concentration of 29 $\mu g \cdot g^{-1}$ of ferrous iron for Scots pine.

It is interesting to speculate on the role of superphosphate in the establishment of the trees. Increased availability of phosphorus would unduly raise the phosphorus/iron ratio and worsen the balance. Yet, Experiment III in particular showed a beneficial effect of superphosphate which may have also been present in Experiment I. Since the superphosphate was added in concentrated form in pockets near the root system, the acid immediate environment of the fertilizer may have allowed normal uptake of iron and therefore its main role may have been that of an acidifier (Reuter et al. 1973).

However, the lesser success with sulphur and manganese sulphate in Experiment III (although creating an environment as acid as that of superphosphate) shows that ready availability of phosphorus may also have been beneficial. The success of sulphur would depend to a large extent on the presence and activity of sulphur-oxidizing organisms. Since *Thiobacillus* requires a low pH for optimum growth most of the sulphur oxidation in the rendzina may be due to heterotrophic organisms which produce little sulphuric acid (Swaby and Vitolins 1968). Ammonium sulphate proved toxic in Experiment III, which may be the result of excessive salt concentrations due to the drying of the soil in summer, especially in such shallow and exposed soils as the rendzina. The alkaline soil of Experiment I provided much more favourable moisture conditions because of the relatively low-lying situation and greater depth of the soil, which undoubtedly contributed to the high growth rates after establishment.

From available evidence, iron deficiency may be the main limiting factor in the establishment phase of radiata pine on the rendzina. It is usually accompanied by abnormal concentrations and ratios of phosphorus, potassium, calcium, and iron. Manganese deficiency may also be present in the establishment phase, but appears to be the main growth limiting factor in the established phase in the absence of unusual concentrations of other elements.

Zinc and copper deficiency occurred in Experiment I in later stages of growth, whereas on the hill-top rendzina only copper deficiency occurred occasionally in well grown trees.

Genotypic differences in tolerance of alkaline conditions were only shown in Experiment III.

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References

CARTER, M.R. 1980. Association of cation and organic anion accumulation with iron chlorosis of Scots pine on prairie soils. Plant and Soil 56:293—300.

— 1981. Association of total $CaCO_3$, and active $CaCO_3$ with growth of five tree species on chernozemic soils. Can. J. Soil Sci. 61:173—175.

CLEMENT, A. 1977. Comparison between the mineral nutrition of *Pinus nigra nigricans* and *Picea excelsa* in very calcareous, calcareous and non-calcareous soils, effects of mineral and organic anions on metabolism. Ann. Sci. For. 34:293—309.

DALE, J., McCOMB, A.L. & LOOMIS, W.E. 1955. Chlorosis, mycorrhizae and the growth of pines on a high-lime soil. For. Sci. 1:148—157.

DeKOCK, P.C. 1964. The physiological significance of the potassium-calcium relationship in plant growth. Outlook on Agric. 6:93—98.

— HALL, A. & INKSON, R.H.E. 1978. Active iron in plant leaves. Ann. Bot. 43:737—740.

GIBBONS, F.R. & DOWNES, R.G. 1964. A study of the land in south-western Victoria. Soil Conservation Authority, Melbourne, Victoria.

INGESTAD, T. 1958. Studies on manganese deficiency in a forest stand. Medd. Stat. Skogsf. Inst. 48:3—20.

KREUTZER, K. 1970. Manganmangel der Fichte (*Picea abies* Karst.) in Süddeutschland. Forstw. Cbl. 89:275—299.

LAATSCH, W. 1967. Beziehungen zwischen Standort, Ernährungszustand und Wuchsleistung von Kiefernaufforstungen im Mittelmeergebiet. Forstw. Cbl: 86:69—81.

LANGE, P. 1969. A manganese deficiency in *Pinus radiata* at Klein Gouna, Knysna. For. in S.A. 10:47—61.

LANUZA, M.J. de 1966. The determination of levels of manganese, boron and molybdenum sufficient for growth of Monterey pine (*Pinus radiata)* and the characterization of deficiency and toxicity symptoms for these three elements. Rep. Inst. For. de Inv. Exp., Madrid.

— 1970. The determination of levels of iron, zinc and copper for growth of Monterey Pine *(Pinus radiata)* and the characterization of deficiency and toxicity symptoms for these three elements. Min. de Agric., Inst. For. de Inv. y Exp., Madrid. Final Report.

Le TACON, F. 1974. La nutrition minérale du Pin noir D'Autriche (*Pinus nigra* Arn. *ssp. nigricans* Host.) sur les plateaux calcaires de l'Est de la France. Ann. Sci. For. 31:83—95.

— 1978. La présence de calcaire dans le sol. Influence sur le comportement de l'Epicea commun (*Picea excelsa* Link.) et du Pin noir d'Autriche (*Pius nigra nigricans* Host.). Ann. Sci. For. 35:165—174.

LOWTHER, J.R. 1980. Use of a single sulphuric acid-hydrogen peroxide digest for the analysis of *Pinus radiata* needles. Commun. Soil Sci. Plant Anal. 11:175—188.

Munsell Color Company Inc. 1952. Munsell Color Charts for Plant Tissues. Baltimore, U.S.A.

NAKOS, G. 1975. Seasonal changes in foliar nutrient concentrations of forest species in the nursery. I. Conifers. Publ. No. 73, Inst. Dasik, Ereunōn, Athens, Greece. [For. Ab. 38, 1977, no. 2083.]

— 1979. Lime-induced chlorosis in *Pinus radiata.* Plant and Soil 41:573—588.

NELSON, L.E. & SELBY, R. 1974. The effect of nitrogen sources and iron levels on the growth and composition of Sitka spruce and Scots pine. Plant and Soil 41:573—588.

REUTER, D.J., HEARD, T.G. & ALSTON, A.M. 1973. Correction of manganese deficiency in barley crops on calcareous soils. II. Comparison of mixed and compound fertilizers. Aust. J. Exp. Agric. Anim. Husb. 13:440—445.

SEELIGER, M.T. & MOSS, D.E. 1976. Correction of iron deficiency in peas by foliar sprays. Aust. J. Exp. Agric. Anim. Husb. 16:758—760.

STONE, E.L. 1968. Microelement nutrition of forest trees: A review. In "Forest Fertilization: Theory and Practice". Tenn. Vall. Auth., Muscle Shoals, Ala.

SWABY, R.J. & VITOLINS, M.I. 1968. Sulphur oxidation in Australian soils. Trans. Ninth Inst. Soil Sci. Congress, Adelaide, Australia 4:673.

THEMLITZ, R. 1958. Ein Beitrag zur Düngung in forstlichen Pflanzgärten. Beobachtungen zum Kalk-Kali-Antagonismus bei jungen Nadelholzpflanzen. Kalibriefe 6:1—10.

WALLIHAN, E.F. 1966. Iron. In "Diagnostic Criteria for Plants and Soils". (Ed. H.D. Chapman.) Univ. Calif., Div. Agric. Sci.

WATANABE, F.S., LINDSAY, W.L. & OLSEN, S.R. 1965. Nutrient balance involving phosphorus, iron and zinc. Soil Sci. Soc. Amer. Proc. 29:562—565.

WEHRMANN, J. 1964. Folgen übermässiger Kalkanwendung im Pflanzgarten. Mitt. Staatsf. verw. Bayerns, München 34.

ZECH, W. 1969. Beitrag zur Kenntnis der Nährelementgehalte in Latschennadeln *(Pinus montana).* Forstw. Cbl. 88:178—186.

— 1970a. Besonderheiten im Ernährungszustand chlorotischer Fichten auf kalkreichen Böden. Forstw. Cbl. 89:1—9.

— 1970b. Nadelanalytische Untersuchungen über die Kalkchlorose der Waldkiefer (*Pinus silvestris*). Z. Pfl. Ern. Bodenk. 125:1—16.

Total of 31 references

PREVENTING THE GROWTH DISTURBANCES IN PINE CULTURE BY PINE-BARK FERTILIZATION

Alojzy Kowalkowski and Jan Sytek

The aim of this paper is to inform on the results of the investigation that has been taken up in order to establish the possibility to preventing the growth deformations in young pine-cultures by using the bark as the means of ameliorating the soils.

The investigation took place on the area of some hundred hectars of degraded post-farming automorphic and poorly developed rusty soils formed of fluvial sand of Vistulian glaciation age in the Narew river valley. In the spring the year 1971 on 4 surfaces of an aggregate area of 10.5 ha unthrifty pine stands 40—45 year old were removed. In the spring of the year 1972 fragmented pine bark of a fresh-stored up in damp and composted type was spread in doses of 200, 400 and 800 m^3/ha. A part of the bark was plowed-in to the depth of 20 cm, and a part of it was left on the soil surface. A 1-year old common pine with the biocoenotic unit admixture of birch and alder was planted in April 1972.

After 5 years, although a height-increment has undoubtly been obtained as a result of bark waste fertilization, no ultimate conclusions can be drawn with respect to long-term effect of nutrients made progressively available from the bark decomposition.

Out of the three bark types employed for ameliorating the degraded rusty soil, it is the bark stored-up 2—3 years in the dump that has the most advantageous effect upon the height-increments in pine cultures. The effect of the fresh and composted bark is equivalent though markedly weaker. The 400—500 m^3/ha bark doses are the most effective.

Introduction

Pines belong to the species that possess the capability of adapting their growth to the water- and nutrient supply (Mälkönen 1974, Przybylski 1970, Miller et al. 1978). The adaption capability of young pine that grow on young or devastated soils particularly deficient in humus and nutrients, manifests itself in diminution of the height-increment, flattering of the crowns, dying of the top-shoots or of the lower plant parts. In extreme cases there arise umbrella-like and shrub-like forms or trees with procumbent branches. Common pines in 10—20 year old cultures are frequently 20—60 cm high and there is little chance for them to reach a normal height.

In spite of the fact that the above described deformations have recently been linked with the effect of industrial emission (Wolak 1970, Tamm and Aronsson 1972, Greszta 1975, Swieboda 1980), they probably were primarily brought about by water- and nutrient-deficiency in the soil. Since the problem of deformations is becoming increasingly serious and there is simultaneously accumulation of large amounts of barking waste, investigation has been taken up in order to establish the possibility of preventing the growth deformations in young pine-cultures by using the bark as the means of ameliorating the soils.

The purpose and the methods of investigation

The investigation took place on the area of some hundreds of hectars of degraded post-farming rusty soils in the valley of the river Narew at the confluence of the rivers Narew and Bug (Kondracki 1977, Fig. 1). On 4 surfaces of an aggregate area of 10,5 ha 40—45

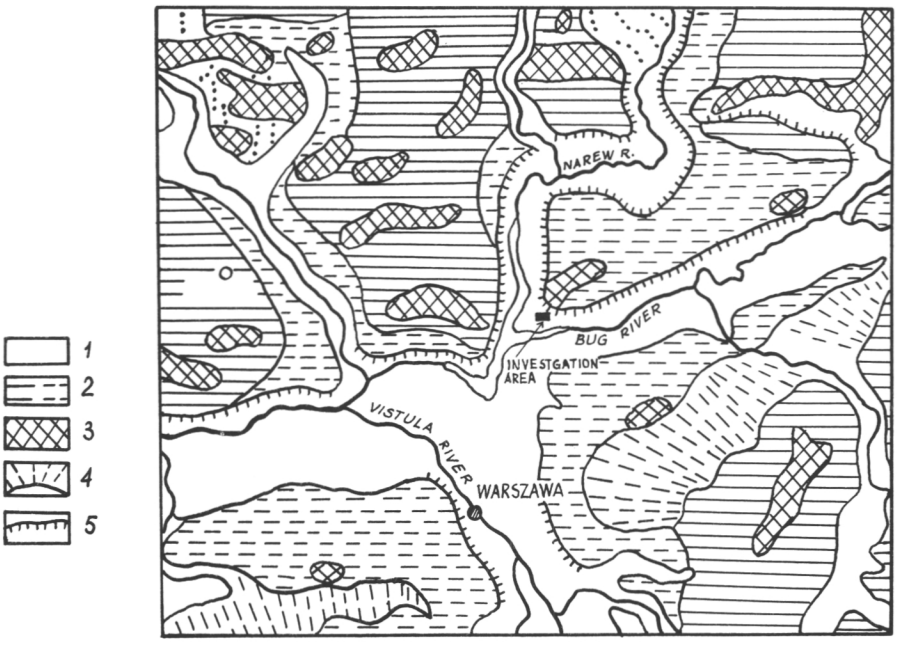


Figure 1. Study-area location in the valley of the river Narew against the geomorphological background of the surrounding terrains (According to Kondracki 1977).
Legend: 1 — bottom of valleys and depressions, 2 — ground-moraine uplands of Central Polands glaciation (Riss) and their depressions, 3 — terminal-morains zone, 4 — outwash slopes, 5 — steep valley-edges.

year old unthrifty pine-stands were removed in the spring the year 1971, those pine-stands showing growth disturbances (Photos 1 and 2). After plowing the surfaces to the depth of 60 cm, yellow lupin was sown, as green fertilizer, in the quantity of 120 kg/ha. In the spring of the year 1972 fragmented pine-bark of a fresh-stored up in dump- and composted type was spread in doses of 200, 400 and 800 m^3/ha, the bark originating from the Paper and Cellulose Plant in Ostroleka. A part of the bark was plowed-in to the depth of 20 cm and a part of it was left on the soil surface. A 1-year old common pine with the biocoenotic unit admixture of birch and alder was planted in April 1972. In the same year, on the surfaces 1 and 2, aircraft fertilization was carried out in the following quantities: N — 40 kg, P —50 kg, and K — 60 kg/ha. In the year 1973 N-fertilization was repeated by a dosis of 40 kg/ha; the surfaces 3 and 4 being excluded from fertilization.

After 5 years, in the year 1976, the pine-cultures showing good growth were subjected to preliminary studies on the effects of bark- and mineral fertilization. The present paper presents the results of the studies on the surface 4, i.e. concerning the effect of fertilizing by three types of bark in three doses, on both the soil surface and plowed-in.

The soil samples from the profile were subjected to an analysis of: the chemical composition in the Na_2CO_3 alloys, the mechanical composition — by the Bouyoucos method as modified by Casagrande and Prószyński, pH — by the potentiometric method, exchangeable cations — in 1N eluate of CH_3COONH_4 solution with pH 7,0, exchangeable acidity — by the Daikuhara method, exchangeable Al — by the Sokolov method, hydrolytic acidity — by the Kappen method, total N —by the Kjeldahl method, C org. — by the Tyurin method and easily soluble forms of N—NH_4, N—NO_3, S—SO_4, P, K, Ca, and Mg in the extract of 0.03N CH_3COOH. The specific density was determined by the pycnometric method, while volumetric density, current humidity, maximum capillary water capacity and total porosity were determined in samples of a natural structure and contained in cylinders of a capacity of 100cc.

In the barking waste the grain, size composition was determined by the sieving method, pH — by the potentiometric method, total N — by the Kjeldahl method, oxidable carbon — by the modified Tuyrin method, total P, Mg, S, K and Ca content — in the wet-burned material, the content of easily soluble forms of N—NH_4, N—NO_3, S—SO_4, P, K, Ca and Mg in the 0.03N CH_3COOH eluate and the total Ca, Mg, K, Na, and P desorptivity — by the method of electrodialysis.

In the spring of the year 1977 measurements of the growth-in-height of pines in 1972—1976 were performed with an accuracy to 1 cm. On each surface 90 trees were measured and the arithmetic mean was calculated. In November 1976 on each surface 5 samples of 1-year old needles were taken from the shoots of the top whorl. The morphometric measurements of needles were made, and their chemical composition was determined after burning them wet.



Photo 1. Common pine about 45-year old with dead top-part, parts of the middle and lower crown transformed into weeping branches.



Photo 2. 45-year old pine about 2 m high with hanging and procumbent branches.

Investigation results

Description of soils

The profile properties and structure of the automorphic and poorly developed rusty soils formed of fluvial sands of Vistulian age of different grain-size (Fig. 2), are determined by the genesis of their parent material, the periglacial transformations as well as by man's economy.

Rusty soils (subarctic brown soils) with the Bv-/Bv/-C horizons were formed in the late pleistocene of noncarbonate sands containing up to 2 per cent of floatable parts, 1—3 per cent of silt fractions and traces of skeleton parts. Owing to the frost weathering there was in these sands an increase in the content of floatable parts in the Bv horizons up to 4—6 per cent, and in the content of silt fractions — up to 4—7 per cent. The initial high quartz-content of 83—87 per cent in these soils results in a high SiO_2-content of 94—96 per cent, as well as in a very low Fe, Ca, Mg, K and Mn content (Table 1).

Natural lability of the mineral components, and high susceptibility of the soil in question to the action of external factors is illustrated by the small sums of exchangeable cations, low sorption capacities, as well as by very low base saturation in mineral horizons (Table 2). Although, in the Bv horizon the humus content approaches to that typical of the relic horizon of periglacial origin (Kowalkowski et al. 1981), the humus content in the arable layer indicates the poor biological activity of those soils. In addition to high C:N ratios (Table 3), this poor biological activity is also testified by slightly developed litter Ol and raw-humus Ofh

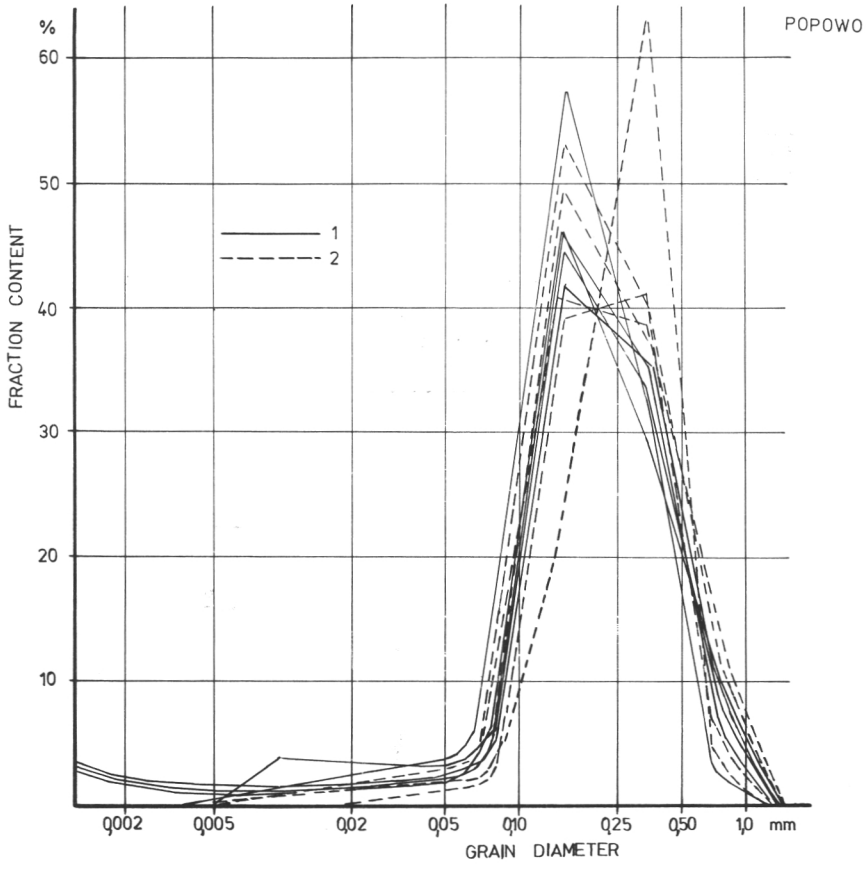


Figure 2. Graining curves of soils and parent-rocks on the experimental surfaces.
Legend: 1 — soil horizon graining, 2 — fluvial sediment graining in the subsoil.

Table 1. Total chemical composition of soil on the experimental surface No 4

Soil horizon	Sampling depth cm	Losses of ignition %	Content in dry mass percentage									
			SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	P_2O_5	MnO	CuO	ZnO
reAp, reApE	0—5	1,42	94,30	2,55	0,44	0,13	0,03	0,28	0,12	0,009	0,006	0,009
reApBvJ	5—15	0,92	95,08	2,74	0,46	0,13	0,03	0,29	0,12	0,009	0,004	0,009
C_1 or	15—38	1,33	95,84	2,44	0,26	0,13	0,03	0,29	0,07	0,005	0,002	0,009
C_2	38—130	0,38	95,27	2,61	0,23	0,13	0,05	0,31	0,07	0,005	0,004	0,012

Table 2. Exchangeable cation composition and sorption soil-properties

Soil horizon	Sampling depth cm	Exchangeable cations in me/100 g of soil					Hh me	Th me	Vh %	Number of samples under study
		Ca^{2+}	Mg^{2+}	K^+	Na^+	S				
Ol	2—1	4,33	1,47	1,43	0,29	7,52	28,52	36,04	20,9	3
Ofh	1—0	3,97	1,24	0,59	0,19	5,99	23,80	29,79	20,1	2
reAp, reApE	0—15	0,11	0,04	0,02	0,03	0,20	3,94	4,14	4,8	4
Bv, BvJ	15—/15/50	0,05	0,03	0,02	0,02	0,12	2,67	2,79	4,3	5
/Bv/	50—70	0,04	0,02	0,01	0,02	0,09	1,26	1,35	6,7	6
C	from /15/70	0,13	0,05	0,02	0,03	0,23	1,06	1,29	17,8	8

Table 3. Major chemical properties of soils investigated

Soil horizon	Sampling depth cm	C_{org} %	N_{total} %	C:N	pHKCl	Number of samples under study
Ol	2—1	41,74	1,22	34,2	3,2—3,7	3
Ofh	1—0	28,98	0,98	29,6	3,2—3,6	2
reAp, reApE	0—15	0,78	0,05	15,6	4,0—4,2	4
Bv, BvJ	15—/15/50	0,37	0,02	18,5	3,9—4,7	5
/Bv/	50—70	0,09	0,01	9,0	4,7—4,9	6
C	from /15/70	0,05	0,007	7,1	4,4—5,1	8

Table 4. Major physical and water indices of soils investigated

Soil horizon	Sampling depth cm	Specific density g/cm^3	Volumetric density g/cm^3	Total porosity per cent	Maximum capillary water capacity per cent	Maximum cap. water capacity in total porosity percentage per cent	Number of samples under study
Ol	2—1	1,43	.	.	.	.	3
Ofh	1—0	1,63	.	.	.	.	2
reAp, reApE	0—15	2,61	1,42	46,5	30,6	65,8	8
Bv, BvJ	15—/15/50	2,63	1,47	44,7	28,7	64,2	8
/Bv/	50—70	2,64	1,55	41,2	24,6	59,7	6
C	from /15/70	2,65	1,54	41,5	29,7	71,6	8

horizons, which cover the soil surface to the extent of scarcely 50—60 per cent.

The mineral composition and the colloid content result in high total porosity of over 41 per cent throughout the profile depth, and in the relatively low value of the maximum capillary water capacity (Table 4). Consequently, in those soils there exist unfavourable conditions for retaining the precipitation waters. As a result of this there is periodical water deficiency within the range of tree roots as well as leaching of the soluble organic and mineral substances. The mechanical farming brought, on large areas, a partial or total destruction of the Bv horizon, while the intensive denudation and deflation processes uncovered nonproductive and dry sands from the subsoil.

Major properties of barking waste

The properties of the barking waste used in the experiment are considered from the angle of their ameliorative effect upon the physical and chemical soil properties.

The pine-bark fragments with timber admixture produced during mechanical barking are mainly composed of parts of 20—2 mm as well as less than 0.1 mm. (Fig. 3). The grain-size composition of the bark types under consideration does not undergo major changes during the 2 to 4 year storing-up period in the dump, as well as during the composting process.

Table 5. Major physical and water properties of pine barking-waste

Bark type	Current humidity per cent	Maximum capillary water capacity per cent	Field water capacity	Volumetric density g/cm^3
Fresh bark	24,46	43,86	27,64	0,37
Dump bark	25,48	44,55	26,65	0,33
Composted bark	19,29	41,32	25,92	0,41

Inconsiderable differentiation of the physical and water properties in the three types of the pine-bark under study (Table 5) indicates the resistance to the biological decomposition even under conditions of slightly acid reaction in the composted bark (Table 6).

According to Kuhlman (1970) after 6 weeks of incubating the bark with 15 species of soil and symbiotic fungi there is a mass decrement of 3 to 12.3 per cent, while further incubation up to 12 and 18 weeks brings about only inconsiderable de-

Table 6. Chemical composition of pine barking-waste

Bark type	pH		$C_{org.}$	N_{total}	C:N	Ca	Mg	P	K
	H_2O	KCl	per cent	per cent		per cent			
Fresh bark	5,7	4,7	43,8	0,40	109,5	2,60	0,14	0,042	0,060
Dump bark	6,9	5,6	44,0	1,02	45,0	1,78	0,13	0,066	0,086
Composted bark	6,8	5,5	45,5	1,32	34,5	1,82	0,22	0,057	0,065

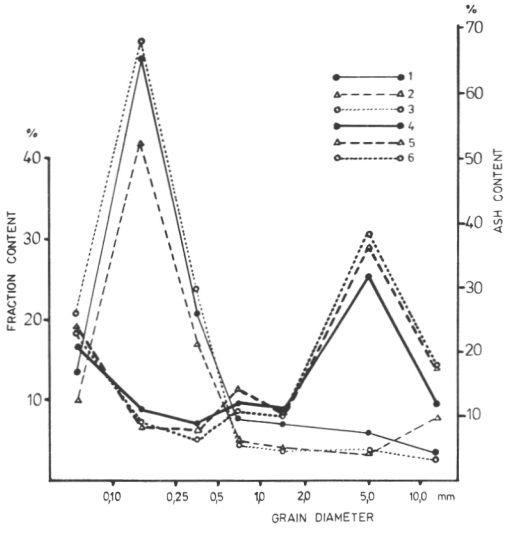


Figure 3. Size-composition of pine barking-waste, and ash content in respective fractions.
Legend: ash content: 1 — fresh bark, 2 — dump bark, 3 — composted bark; graining: 4 — fresh bark, 5 — dump bark, 6 —composted bark.

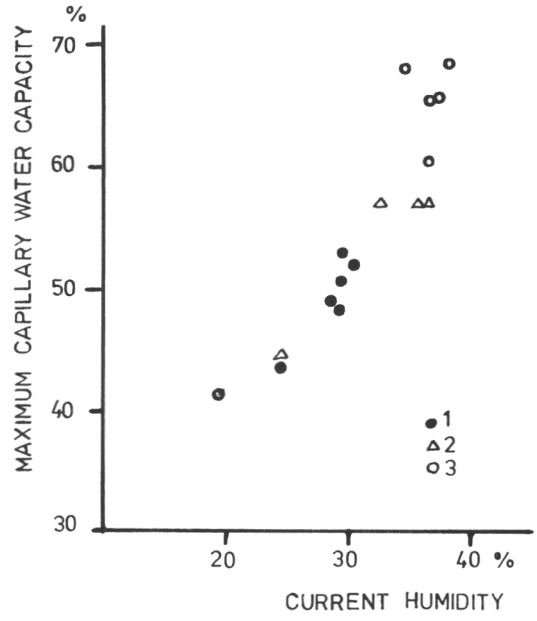


Figure 4. Relationship between current humidity and maximum capillary water capacity in three types of barking-waste employed in the experiment.
Legend: 1 — fresh bark, 2 — dump bark, 3 — composted bark.

crements. Owing to the toxic or inhibitory components, that limit the growth of the fungi (Schefter and Cowling 1966, Kuhlman 1970), the bark undergoes no decay either in the soil or upon its surface.

The maximum infiltration capacity that amounts up to 240 per cent as well as the very slow moistening (Bauza 1981) are the factors regulating the bark current humidity as well as the, variable in time, water field capacity and maximum capillary water capacity of the bark. The latter two correlate with the current humidity (Table 5, Fig. 4).

Pine barking waste as the source of nutrients is poor in nitrogen, magnesium and potassium (Table 6). Although the storing-up of the waste in dumps as well as its composting do not substantially change its grain-size composition, the chemical composition is subjected to definite transformations under the influence of the organic and mineral substances added during the composting (Table 6). These transformations results also from the leaching of the mobile organic substances and mineral components. In consequence of these processes there is an increase in the nitrogen content, which is evident from the C:N ratios that deviate considerable from those of the fresh bark.

There is also an increase in the content of Mg and P, while the content of Ca decreases. At the same time, however, both in the bark from the dump and in the composted one, there is a substantial increase in the mass of the easier soluble

Table 7. Mineral-component content in pine barking-waste, the components being soluble in 0,03N CH_3COOH

Bark type	$N\text{-}NH_4$	$N\text{-}NO_3$	N	Ca	Mg	P	K	$S\text{-}SO_4$
	mg/100 g of bark abs. dry							
Fresh bark	0,62	1,13	1,75	54,45	10,75	10,33	10,20	1,35
Dump bark	64,57	12,46	77,03	26,51	8,62	28,29	16,37	0,84
Composted bark	06,02	8,55	104,57	14,00	5,58	40,39	17,22	1,54

components which can pass into the soil solutions and can be included into the biological circulations. To these components belong: mineral N, phosphorus and potassium. Whereas there is a decrease in the content of the easier soluble forms of calcium and of magnesium (Table 6 and 7). Consequently, considerable quantities of calcium (Table 8) are durable linked with the bark and do not mitigate the intensely acid reaction of the soils under study (Table 3). The barking-waste poor in magnesium doesn't modify the acute deficiency of this component in the soil, but it is a relatively good source of potassium and phosphorus (Tables 7 and 8).

The main source of the nutrients are the bark fractions less than 0.05 mm, which is evident from their high ash content. Although the low ash content of the coarser fractions i.e. greater than 0.05 mm is not differentiated in the bark types under consideration, the ash content in fractions less than 0.05 mm is the highest in the composted bark and the lowest in the dump-bark. The ash content differences are not, however, as great as to be able to determine the sequence of ion releasing from the bark in the process of electrodialysis. In the bark types under study, characterized by the sequence of total $P_2O_5 > Ca > K > Na > Mg$ ion release in the first phase of the electrodialysis, it is P whose desorption is the easiest, and it is Ca whose desorption is the most difficult.

Chemical composition of the pine needles and growth of the pine culture

In the 5 year period the bark applied to the soil surface had a positive effect upon the growth-in-height of the pine seedlings

Table 8. Minimal and maximal nutrient-mass in kg/ha introduced into soil with pine barking-waste in the experiment.

Nutrients	Bark types in m^3/ha					
	Fresh bark		Dump bark		Composted bark	
	200	800	200	800	200	800
Ca	1030	4120	123	492	620	2480
Mg	2	8	18	72	42	168
K	139	555	119	474	110	440
Na	20	82	19	75	19	75
P	34	137	86	345	406	1623

(Table 9). The best results, in comparison with the non-fertilized surface, were obtained by using the dump bark. The dosis 400 m^3/ha brought about the increases in the growth-in-height by 61.3 per cent. Poorer results — 41.4 per cent — were obtained with the dosis of 800 m^3/ha and the worst results — with the dosis of 200 m^3/ha. The application of fresh and composted bark to the soil surface resulted in the normal growth of young trees as well, the greatest height-increments of 119—120 per cent being obtained with the dosis of 400 m^3/ha, and lower height-increments of 103—106 per cent — with the bark dosis of 200 and 800 m^3/ha.

The height-increment dynamics was different in the case of the plowed-in bark. The dosis of 800 m^3/ha slowed down the height-increment of pine seedlings during a few succeeding years, the composted bark in a 3-year period, the raw bark in a 2-year period and the dump-bark during the first year. In later years the increasing height-increments of the pine were found with the dosis of 800 m^3/ha (Photo 3), exceeding the increments with the doses of 200 and 400 m^3/ha. In the first 5-year period the dump-bark showed the best performance, causing the increase in the growth-in-height by 45,3 per cent with the dosis of 400 m^3/ha, by 40.5 per cent with the dosis of 800 m^3/ha, and by

Table 9. Effect of pine barking-waste fertilization upon height-increment of pines, on plot No 4.

Bark type	Dosis	Mean annual height-increment in cm					Total
	m^3/ha	1972	1973	1974	1975	1976	height in spring 1977
Bark plowed in							
Fresh bark	800	4,34	8,67	19,14	22,39	34,75	89,29
	400	5,54	10,43	22,54	16,26	28,01	82,80
	200	7,10	9,94	18,15	19,51	30,58	85,28
Dump bark	800	4,65	10,17	21,98	21,22	36,11	94,12
	400	6,88	12,51	26,53	20,30	31,14	97,35
	200	7,65	10,91	20,22	20,23	34,13	93,32
Composted bark	800	4,85	7,50	15,84	18,32	30,62	77,14
	400	5,86	12,47	28,32	27,74	31,23	95,73
	200	6,41	10,45	20,40	19,69	28,62	85,57
No bark	0	5,24	9,44	18,48	14,08	19,79	67,01
Bark on surface							
Fresh bark	800	5,16	7,62	15,21	17,63	24,61	70,20
	400	5,55	8,95	19,72	17,35	29,75	81,34
	200	4,64	8,04	18,01	17,99	22,97	71,64
Dump bark	800	5,41	8,07	20,20	19,88	35,27	88,98
	400	7,38	11,18	26,39	24,20	39,80	109,27
	200	6,88	10,16	21,00	18,31	28,21	85,56
Composted bark	800	5,29	8,20	18,39	19,68	28,28	79,85
	400	5,65	9,32	19,68	17,73	28,03	80,43
	200	6,03	9,91	16,66	14,78	22,64	70,07
No bark	0	4,34	7,14	17,13	14,66	24,47	67,75

39.3 per cent with the dosis of 200 m^3/ha. The action of the fresh-bark doses was equally uniform, since it increased the height-increments by 28—32 per cent. The least uniform was the action of the composted bark, since it increased the height-increments by 28 and 15 per cent with the doses of 200 and 800 m^3/ha, the highest increase being of 43 per cent with the dosis of 400 m^3/ha.

Whereas the growth of seedlings on the surfaces with no bark-fertilization was not uniform. As early as in the first years 40 per cent of plants showed the dying of top-shoots and transformation of plants into shrubs 10—60 cm high. The needles of these plants were poorly developed, and in the period from the autumn to spring in intensively yellow colouring, with brown necroses at the end of the needles. Initially, the remaining 60 per cent of the plants showed the normal growth, with the lapse of time, however, the individual plant demonstrated chloroses and shortened needles in the top-shoots or their decay throughout, which indicates the lack of equilibrium in the balance of nutrients. (Photo 4).

The analysis of the chemical composition of the one-year old needles indicated both on the fertilized and the non-fertilized surfaces, that the content of the basic nutrients was appreciably lower than that typical of pine-stands in Poland, which according to Szczubialka (1981) is on the average for N — 1.69, P — 0.16, K — 0.52, Ca — 0.25 and Mg — 0.12 per cent (Table 10).

The concentration of nutrients in the needles in all combinations borders on the state of deficiency. That could not even be prevented by high 800 m^3/ha dosis of barking waste, rich in Ca, P, and K compound (Tables 8 and 10). Nevertheless a higher nutrient-content in pines occurs on the surface with the bark plowed-in. Out of the three types of bark the best result was obtained with the plowed-in dump-bark in all doses, as well as with the bark applied to the soil surface in doses of 400 and 800 m^3/ha (Table 10). An extremely low magnesium content was found in the needles on all combinations. On combinations

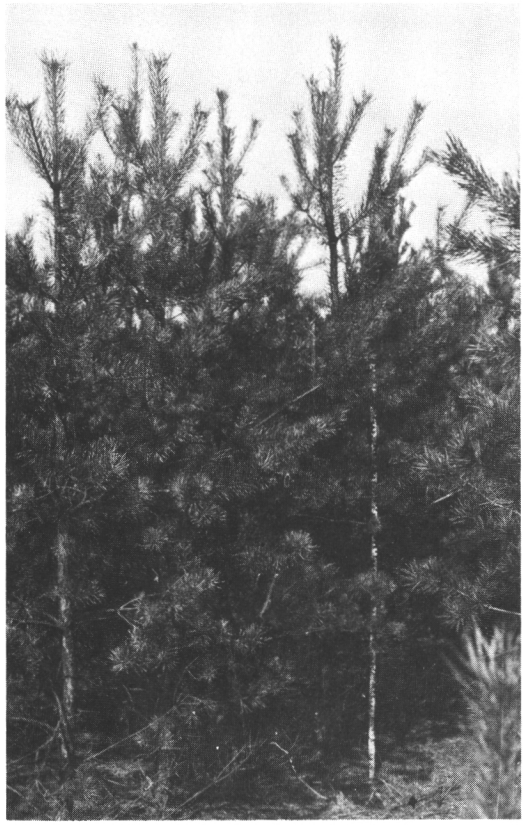


Photo 3. 10 year old common pine over 3 m high, dump bark fertilized with a dosis of 800 m^3/ha.



Photo 4. 10 year old common pine 35 cm high with no bark-fertilization.

fertilized by plowed-in bark the nutrient-concentrations in needles of approximately normal development, of an average mass of 100 needle pairs of 2.7—4.0 g (i.e. of features close to those of needles on nonfertilized plots) — are low. This, in all probability, constitutes the dilution effect caused by producing a considerably larger plant mass.

Summary

Although a height-increment has undoubtedly been obtained as a result of barking-waste fertilization, no ultimate conclusions can be drawn with respect to long-term effect of nutrients made progressively available from the bark under decomposition. In the first phase under consideration of the experiment the chief effect of bark consisted in ameliorating the soil water-conditions, while in the next phase — in enriching the circulation of nutrients and organic substance. In this phase an extra nitrogen, magnesium and potassium mineral fertilization will be necessary.

Out of the three bark types employed for ameliorating the degraded rusty soils formed of the glacifluvial sands, it is the bark stored-up 2—3 years in the dump that has the most advantageous effect upon the height-increments in pine cultures. The effect of the fresh and composted bark is equivalent though markedly weaker. The 400—500 m^3/ha bark doses are the most effective. In view of the transportation costs the bark doses not exceeding 500 m^3/ha are profitable. The acid, carbonateless soil, poor in humus and nutrients is more responsive to 600—800 m^3/ha doses.

Table 10. Effect of pine barking-waste fertilization upon chemical composition of needles in 5-year old culture on the plot No 4.

Bark type	Dosis m³/ha	N	P	K	Ca	Mg	Na	S
		In dry-mass percentage						
Bark plowed in								
Fresh bark	800	1,20	0,12	0,33	0,13	0,065	0,002	0,08
	400	1,35	0,13	0,35	0,15	0,053	0,003	0,09
	200	1,23	0,13	0,36	0,15	0,076	0,002	0,05
Dump bark	800	1,21	0,14	0,34	0,16	0,077	0,002	0,06
	400	1,33	0,13	0,33	0,15	0,071	0,002	0,08
	200	1,38	0,14	0,37	0,14	0,074	0,002	0,06
Composted bark	800	1,23	0,11	0,31	0,12	0,059	0,002	0,10
	400	1,40	0,13	0,38	0,15	0,066	0,003	0,07
	200	1,27	0,14	0,32	0,14	0,054	0,002	0,05
No bark	0	1,28	0,11	0,29	0,12	0,040	0,002	0,07
Bark on surface								
Fresh bark	800	1,35	0,14	0,28	0,17	0,047	0,003	0,09
	400	1,46	0,13	0,33	0,15	0,043	0,003	0,06
	200	1,31	0,11	0,30	0,13	0,039	0,002	0,05
Dump bark	800	1,42	0,14	0,41	0,18	0,077	0,002	0,07
	400	1,46	0,14	0,39	0,16	0,062	0,002	0,09
	200	1,18	0,13	0,29	0,14	0,055	0,002	0,07
Composted bark	800	1,38	0,14	0,31	0,14	0,049	0,003	0,08
	400	1,45	0,13	0,29	0,15	0,048	0,002	0,10
	200	1,36	0,14	0,29	0,15	0,040	0,002	0,06
No bark	0	1,40	0,15	0,36	0,12	0,040	0,003	0,10

References

BAUZA J. 1981. Właściwości fizyczne i mechaniczne korowiny sosny pospolitej (*Pinus silvestris* L.). Konf. Nauk. Techn. Utylizacja kory waznym problemem ochrony środowiska. NOT. Kraków. p. 23—35.

GRESZTA J. 1975. Wplyw imisji na siedliska borowe i drzewoszany sosnowe w ślasko-krakowskim Okregu Przemyslowym. Studia Nat.A.10: 1—184.

KONDRACKI, J. 1977. Regiony fizycznogeograficzne Polski. Warszawa.

KOWALKOWSKI, A., BORZYSZKOWSKI, J. & POREBSKA, G. 1981. Geoekologiczne podstawy rozpoznawania, klasyfikacji i kartografii gleb rdzawych. IBL. Warszawa-Sekocin.

KUHLMAN, E.G. 1970. Decomposition of loblolly-pine bark by soil- — and root inhabitating fungi. Can. J. Bot. 48: 1787—1793.

MÄLKÖNEN, E. 1974. Annual primary production and nutrient cycle in some Scots pine stands. Commun. Inst. For. Fenn. 84(5):1—87.

MILLER, H.G., COOPER, J.M., MILLER J.D. & PAULINE, O.J.L. 1979. Nutrient cycles in pine and and their adaption to poor soils. Can.J.For.Res. 9:19—26.

PRZYBYLSKI, T. 1970. Morfologia. Sosna zwyczajna Pinus silvestris L., PWN Warszawa-Poznań.

SCHEFTER, T.C. & COWLING, E.B. 1966. Natural resistance of wood to microbial deterioration. Annu. Rev. Phytopatol. 4.:147—170.

SWIEBODA, M. 1980. The impact of industrial air pollution on the Scots pine, *Pinus silvestris* L., in the area between the "Boleslaw" lead and zinc smelting works and the Ojców National Park. Ochrona Przyrody, 43:329—361.

SZCZUBIALKA, Z. 1981. Zawartość azotu i skladników mineralnych wigglach jako podstawa oceny stanu zaopatrzenia sosny zwyczajnej *(Pinus silvestris* L.) w skladniki pokarmowe. Doct. diss. Warszawa pp. 80.

TAMM, C.O. & ARONSSON, A. 1972. Plant growth as affected by sulphur compounds in polluted atmosphere. A. Literature surv. Res. Not. 12., Dept. For. Ecol. and For. Soils, Royal Coll. of For. Stockholm.

WOLAK, J. 1970. Modifications in pine *(Pinus silvestris)* under the impact of industrial air pollution. 2. Sylwan, p. 33—39.

Total of 13 references

GROWTH DISTURBANCES AND DIFFERENT DIE-BACKS OF SCOTS PINE IN NORTHERN FINLAND

Risto Jalkanen

As a result of the short growing period and cold climate different types of crown damage is common on Scots pine in northern Finland. The primary or main reason for the damage is often very difficult to define. Different types of pure growth disturbances caused by an imbalanced nutrient status can be found on peatlands, but all the dead, dry crowns are not a result of nutrient imbalances. Abiotic factors such as frost and freeze drying can damage shoots in naturally-regenerated stands and fertilized forests both on mineral soils and peatlands, especially after refertilization. Many fungi and insects are associated with die-back and abnormalities of Scots pine crowns.

Introduction

Northern Finland differs from southern and Central Finland as forestry land in many respects. The growing period is short, the climate is cold and often so rainy that Scots pine (*Pinus sylvestris* L.) populations have difficulties in wintering. This leads to a susceptibility to diseases and abiotic disorders and die-backs. It it thus difficult to distinquish the primary reason for injuries, which is often a result of a complex number of factors. A nutrient imbalance which has no visible growth disturbances can be the primary reason. The pines then become susceptible to diseases and disorders which have visible symptoms.

Different types of growth disturbances, starting with "rat-tail" leader as shown by Kolari (1979), can be found in peatlands in northern Finland. However, it is unclear in such cases whether the leader of a pine has been killed by cold or freeze drying. Peatlands are colder than the surrounding mineral soil sites. Freeze drying is a common cause of top die-back in pine growing on mineral soils in northern Finland. It results in the death of the old leader and the formation of new leaders from side branches. When this continues year after year the tree finally takes on a bushy form. Nutrient imbalance can advance this phenomenon.

The explanation for freeze drying is as follows: roots in frozen peat in light, sunny spring days with white snow, when temperature is exceptionally high in the daytime warming the needles and stems and cold during the next night freeze the dried shoots of a tree which lacks water. When this happens to the tree for the first time, the length of the leader and shoots are normal. However, this is not the case in the pure growth disturbance described by Kolari (1979).

The use of too heavy nitrogen fertilization makes pines susceptible to frost and freeze drying. In the mildest case, freeze drying turns the needles brown only and they are then shed. The buds stay alive. When the injury is more severe, the top of the pine dies. The more nitrogen the tree receives, the stronger the injury is. This is one reason for stem changes a few years after refertilizing peatlands. This kind of dead top can resemble *Cronartium flaccidum* Alb. & Schw. damage. In the most severe cases — after fertilizing in the late spring — the leader and current year shoots become shorter than when a smaller amount of fertilizer is applied, and they may even die already during the same growing season. This can occur with normal forest improvement fertilization. Under-developed shoots can be found in young pine stands, too, when silvicides are used.

Very heavy pine crown damage has been found in nitrogen fertilization areas surrounding the Kolari limestone mine (Grid

27° E 748:35): the fertilizer nitrogen together with lime dust results in the luxurious needles and shoots freezing during the winter.

On sandy pine heaths, typical naturally-regenerated areas in northern Finland, the crowns of young trees can die and round off and form many new leaders. The reason for this has not been studied but it may possibly be due to the overstocking of the stand and thus to nutritional problems of the root system.

Gremmeniella abietina (Lagerb.) Morelet often attacks pines especially in cold, low-lying forest sites, e.g. in river valleys, which are also favoured by root vole (*Microtus oeconomus* Pall.) that eat the bark at the base of the stem thus weakening the tree. This type of vole damage appears as shortened shoots before the tree dies.

Growth abnormalities also appear in northern Finland after the felling of standards, the complete whorls of young trees becoming injured or damaged. The pine crown is also abnormal after attack by *Tomicus piniperda* L. when the timber is stored in the forest after thinning and clear cutting.

Melampsora pinitorqua (Braun) Rostr., attacks the leaders of pine mostly on mineral soil sites, and when infection is heavy, the shoots, too. Partly dead leaders are thicker at the base then than at the top, and they can show "rat-tail" symptoms. However, the fungus produces small wounds in the bark and often there are lateral buds on the short shoots of living healthy base of the leader. In the severest cases, *Melampsora* epidemics can round off the pine.

Literature

KOLARI, K.K. 1979. Hivenravinteiden puute metsäpuilla ja männyn kasvuhäiriöilmiö Suomessa — kirjallisuuskatsaus. Abstract: Micro-nutrient deficiency in forest trees and die-back of Scots pine in Finland — a review. Folia For. 389:1—37.

Total of 1 reference

EXCURSION

The Kivisuo fertilization experimental area

Olavi Huikari and Heikki Veijalainen

Introduction

The Kivisuo experimental area was established in 1959 as a joint effort by the Finnish Forest Research Institute and the National State Board of Forestry.

Kivisuo lies at a latitude of 61°51'N and altitude 125 m. Climatological conditions:

— Annual mean temperature +3 °C
— Annual mean precipitation 550 mm
— Sum of daily mean temperatures (>5 °C) 1300 °C

The Kivisuo area was poor in phosphorus and potassium prior to the fertilization treatments. The pH-values varied between 4,0 and 4,2.

In 1945—47 an area of 100 hectares was drained for hydro-peat drying purposes. The drain spacing is 22 m. There is also a vaulted ditch in the middle of each strip. In 1947—53 the drained area was used as a drying field for fuel peat which was transported from the adjacent peat deposits via pipelines (mixed with water). Prior to this the livig moss was removed and the ground surface levelled off.

The black peat field, without any tree or plant cover, was afforested in 1959. At that time the humified peat cover (residual hydro-peat)) was 5—10 cm thick. This was underlaid in the western parts by a 3-metre deep raw *Sphagnum* peat layer, which was gradually replaced on moving to the east by *Carex*-peats or other more minerotrophic peats. The peat layers are penetrated by mineral soil intrusions in a few locations. The peat on the marginal sites usually contains the remains of trees.

Although the first fertilization experiment was established in 1957, most of them including Exps. I, II and V were laid out in 1959. Exp. XIII was established in 1966 and a number of the experiments were refertilized (including micronutrient treatments) during the 1970's.

Experiment I is a 4×4×4-factorial NPK-experiment with two replications. This means that four levels of N-, P- and K-fertilizers were mixed in all possible combinations.

Experiment XIII contains very heavy fertilization and refertilization treatments with the aim of achieving maximum timber production. Scots pine was planted in rows along the ditch edges in order to:

— give the trees the best possible growing conditions
— enable machines to be used in refertilization, in thinning and felling etc.

Three different planting spacings have been used. A micronutrient experiment is also included.

Experiment II is a 2^4-factorial micronutrient trial with two replications. The micronutrient treatments are fertilizer borate, $CuSO_4$, $MnSO_4$ and $ZnSO_4$ at a rate of 50 kg/ha. All the plots were treated with a heavy NPK basic fertilization.

Experiment V was originally a spot-fertilization trial. In 1966 it was refertilized. A similar refertilization regime was used in experiments I and V. The treatments were as follows:

A = broadcast fertilization, PK 500 kg/ha
B = spot fertilization, PK 125 kg/ha
C = control = no refertilization

Later on, in 1977, an experiment with bark ash was established on three plots along the excursion route. A pruning experiment (1980) has also been established on this incomplete 4^3-factorial experiment.

Growth disturbances became visible at Kivisuo already in the middle of the 1960's, five or six years after the fertilization treatments. They were common in Exp. I,

especially in the western replication, but later on also in some parts of Exp. XIII. In 1975—76, many trees appeared to have recovered in Exp. I. although snow and fungal diseases killed off a large number of them. Acute growth disturbances are still visible in Exp. XIII.

Other experiments at Kivisuo:

III Sowing, planting and fertilization (1957)
IV Different phosphorus and potassium fertilizers (1961)
VI Different tree species and fertilization (1962)
VII Fertilization methods and spruce planting (1963).
VIII Fertilization methods and spruce planting (1964)
IX NPK-mixture trial, pine (1964)
X Fertilization methods and pine planting (1965)
XI 4^3-factorial NPK and pine planting experiment on the original peat substrate (1964)
XII Spot fertilization (1—5 times) (1965—69)
XIV Mulching, sowing and fertilization (a machine trial) (1968)
XV Afforestation with birch + NPK Ca (1969—70)
XVI Frost resistance of trees (1969—70)
XVII Hydrological experiment with different drain spacings (5—50 m) (1966—67)

Some early results and the lay-outs of these experiments are presented in the Finnish guide-book, available at Kivisuo.

Excursion

During the excursion to Kivisuo near Leivonmäki, visits were made to stands showing growth disturbances at different stage of development on pine, to growth disturbance prevention experiments and to extensive series of fertilizer experiments established by the Finnish Forest Research Institute over 20 years ago. The results demonstrated in the field show that vertilization, carried out at the right time and right place, can ensure satisfactory and problem-free growth of trees on peatlands. Refertilization, in particular, carried out without sufficient consideration can result in serious problems. On the other hand the Kivisuo experiments show that if growth disturbances are allowed to develop too far, then not even wood ash fertilizer can rectify the problem. Steps should be taken to rectify growth disturbances the moment the first symptoms appear.

CLOSING ADDRESS

During the workshop and excursion we have heard a large number of excellent papers on growth disturbance phenomena in forest trees and the causes of such growth disorders. The workshop has mainly concentrated on growth disorders caused by micronutrient deficiencies.

Diagnosing growth disorders caused by micronutrient deficiencies and nutrient imbalances on the basis of external symptoms, is only possible if sufficient is known about the basic processes involved in tree growth, about the effect of different environmental factors on the external appearance of trees and also about changes caused by insect and fungal attack. The study of growth disturbances in trees is one of the most difficult tasks which we are faced with in the field of forestry. However, solving these problems may enable us to achieve better forest growth and the utilization of the type of soils which, in the absence of such information, would be exceedingly difficult to utilize for forestry purposes or else remain completely outside the reach of forestry production.

I would like to take this opportunity to thank the participants of this workshop for their excellent cooperation and to wish you all, for the sake of world forestry, every success in solving the growth deficiency problem.

Finally, I would like to thank the chairmen of the Workshop and the Workshop's organizing committee for their fine achievement.

Olavi Huikari

SELOSTE

METSÄPUIDEN KASVUHÄIRIÖT

Jyväskylässä ja Kivisuolla 10.—13. lokakuuta 1982 pidetyn kansainvälisen symposiumin esitelmäraportit

Johdanto

Järjestelmällinen metsänlannoituskoetoiminta aloitettiin Suomessa 1950-luvulla. Lannoitustutkimusten tavoitteena on ollut tarvittavan perustiedon hankinta, ennen muuta eri puulajien ravinnevaatimuksista puuston eri kehitysvaiheissa ja eri kasvupaikoilta käytännön metsätaloudessa. Tähän mennessä on Suomessa lannoitettu hyvin tuloksin metsiä yhteensä n. 2,6 milj. hehtaaria, josta noin puolet on kivennäismaita ja puolet ojitettuja turvemaita.

Koekenttien puustoa mitattaessa havaittiin, että turvemailla puuston kasvu vaihteli paikoittain, ja se saattoi hyvänkin alkumenestyksen jälkeen tyrehtyä nopeasti. Ongelmia selvittelevät tutkimukset aloitettiin prof. Olavi Huikarin toimesta jo 1950-luvulla perustamalla hivenlannoituskoesarjoja. Vuonna 1976 aloitettiin Metsäntutkimuslaitoksessa puiden kasvuhäiriötutkimusprojekti. Sen tehtävä oli häiriöiden kuvaaminen ja tunnistaminen sekä kasvuhäiriöiden levinneisyyden, syiden ja torjuntamenetelmien selvittäminen. Kasvuhäiriötutkimuksella on lisäksi kiinnekohtia taimitarhatuotantoon, metsänviljelyyn, peltojen metsittämiseen ja moniin muihin metsissä suoritettaviin tutkimuksiin, joilla pyritään puun laadun tai tuotoksen parantamiseen.

Puiden kasvuhäiriötutkimusten lisääntyessä Suomessa, Pohjoismaissa ja muualla maailmassa Metsäntutkimuslaitos yhteistyössä IUFRO:n työryhmän S.1.05—01 "Peatland Forestry" kanssa katsoi aiheelliseksi kutsua eri maiden metsäntutkijoita sekä kasvifysiologian ja maaperäkemian tutkijoita yhteiseen työkokoukseen jakamaan tietoa ja kokemuksia tästä aiheesta. Seuraavassa on yhteenveto istunnoissa pidettyjen esitelmien pääkohdista sekä retkeilystä.

Istunto 1. Metsäpuiden kasvuhäiriöt

Suomessa tunnetaan n. 400 kasvuhäiriöaluetta, joista suurin osa on ojitetuilla ja lannoitetuilla turvemailla. Kasvuhäiriöalueiden tiheys on suurin Pohjois-Pohjanmaan ja Keski-Suomen pohjoisosien aapasuo-komplekseissa (alunperin avoimia ja vetisiä saranevoja). Etelä- ja Lounais-Suomi ovat käytännöllisesti katsoen kasvuhäiriövapaita. Arvioitu kasvuhäiriöala on n. 2 % ojitusalueista. Karuilla kasvupaikoilla kasvuhäiriöitä on keskimääräistä vähemmän, kun taas eräillä ravinnerikkaimmilla soilla kasvuhäiriöpuiden osuus on 6—10 %, ts. suurin osa ojitetuista ja lannoitetuista turvemaista on hyväkuntoista ja tuottaa puuta tyydyttävällä tavalla (*Veijalainen, Laine ja Puttonen*).

Norjassa kasvuhäiriöt ovat pääasiassa karujen, lannoitettujen ja metsitettyjen turvemaiden ongelmia, lukuunottamatta n. 20—60 km:n levyistä rannikkovyöhykettä, jossa häiriöitä ei sanottavasti esiinny *(Braekke)*. Ruotsissa kasvuhäiriöt taas ovat turvemaiden ohella metsitettyjen ja typellä lannoitettujen kivennäismaiden ongelmia ja myös siellä on kasvuhäiriöiden puuttuminen rannikkovyöhykkeen alueilla havaittavissa *(Aronsson, Braekke, Möller)*. Pohjoismaissa näyttääkin sekä rannikkovyöhykealueen sadevesien mukana tuleva boori että maiden eteläosien maaperän vesien runsaampi booripitoisuus olevan syynä kasvuhäiriöiden vähäiseen esiintymiseen (*Braekke, Möller, Veijalainen, Wikner*).

Suomessa kasvuhäiriöongelmia on esiintynyt myös taimitarhataimissa. Häiriöiden syyksi on esitetty korkeat rauta- ja pääravinnepitoisuudet (*Raitio*).

Japanilaisten tutkimusten mukaan Indonesiassa esiintyy trooppisten mäntyjen istutustaimilla latvan ns. fox-tailing-ilmiötä (ei si-

vuoksia), jolloin puut katkeavat helposti tuulessa. Häiriön syyksi esitettiin maaperän orgaanisen aineksen, typen ja fosforin runsauden aiheuttamaa ravinne-epätasapainoa *(Kustiaman ym.)*.

Venäläisen tutkimuksen mukaan turvemailla sadevuosia seuraavina vuosina mäntyjen sekä pituus- että sädekasvu häiriintyvät *(Vompersky)*.

Istunto 2. Kasvuhäiriötutkimuksen diagnostiset menetelmät

Suomalaiset tutkijat esittelivät männyn *(Pinus sylvestris)* ja kuusen *(Picea abies)* kasvuhäiriön (dieback) kasvukauden aikaista kehittymistä *(Silfverberg)*, häiriön makro- ja mikroskooppisia oireita silmuissa, versoissa, neulasissa ja juurissa *(Raitio)*, jotka yhdessä Pohjoismaissa havaittujen oireiden kanssa kävivät hyvin yksiin eri puolilta maailmaa tavattujen boorin puutosoireiden kanssa *(Zöttl)*. Lisäksi esitettiin hivenravinnepuutosten ravinnefysiologista taustaa ja biokemiallisia testimenetelmiä *(Kolari)* sekä neulasanalyysin *(Reinikainen ja Veijalainen)* ja ns. kokopuun ravinneanalyysimenetelmän käyttöä kasvuhäiriötutkimuksissa *(Reinikainen ja Silfverberg)*.

Uutena neulasanalyysimenetelmänä esiteltiin PIXE (particle induced X-ray emission), jota vertailtiin konventionaalisiin atomiabsorptio-(AAS) ja spektrofotometrisiin menetelmiin *(Raunemaa ym.)* Männyn neulasissa olevien eri ravinteiden vuodenaikaisten vaihtelujen selittämiseksi esitettiin systeemianalyysiin perustuva ravinteiden sisäinen kuljetusmalli (*Samela ja Raunemaa*). Diagnostisista menetelmistä helpoimmaksi keinoksi kasvuhäiriöriskin ennustamiseksi esitettiin neulasanalyysi yhdistettynä kasvuhäiriöhavaintoihin. Jo ensimmäisten kasvuhäiriöiden esiintymisen havaitseminen on osoittautunut tärkeäksi, mikäli häiriön torjuntaan aiotaan ryhtyä. Millään muulla tavalla ei häiriötä voida riittävän varmasti ennustaa toistaiseksi (*Silfverberg*). Neulasanalyyttisessä tarkastelussa todettiin PK:lla ja NPK:lla lannoitettujen häiriöpuustojen neulasten N, P ja K-pitoisuudet korkeammiksi ja B- ja Cu-pitoisuudet alhaisemmiksi kuin terveissä puustoissa ts. niissä näytti esiintyvän ainakin boorin puutosta, mutta samalla myös pääravinteiden luksuskäyttöä (*Reinikainen ja Veijalainen*).

Istunto 3. Kasvuhäiriön patologiset tutkimukset

Männyn kasvuhäiriöiden yhteydessä Suomessa esiintyvistä sienitaudeista tuotiin esiin sekundaarisina harmaakariste (aiheuttajasieni *Lophodermella sulcigena*) ja versosyöpä (aiheuttajasieni *Gremmeniella abietina)*. Näiden sienitautien esiintymiseen vaikuttavat mm. puiden runsaat pääravinnepitoisuudet sekä häiriöt puiden aineenvaihdunnassa (*Kurkela, Jalkanen*). Männyllä (*Pinus sylvestris*) ja kuusella (*Picea abies*) oli havaittu virusten aiheuttamia muutoksia neulasissa. Niitä olivat mosaikkikloroosi ja mesofyllisolukon erilaiset kloroplastiaberraatiot. Virusperäiseen infektioon viittasivat soluissa havaitut sauvamaiset viruksen kaltaiset partikkelit (*Soikkeli*).

Istunto 4. Kasvuhäiriön ravinnetutkimukset

Suomessa on turvemailla lannoitus PK:lla ja NPK:lla antanut hyviä pituuskasvutuloksia männyntaimikoissa. Lannoitus on hieman alentanut turpeen pintakerroksessa vesiliukoisen B:n ja happoliukoisen Zn:n määriä ja lisännyt happoliukoisen Cu:n määrää.

Neulasten boorimäärät ovat alentuneet asteittain koealajärjestyksessä O-P-PK-NPK. Cu-määriin lannoituksilla ei ole ollut vaikutusta, mutta Zn-määrät ovat alentuneet kaikissa tapauksissa. *(Mannerkoski ja Miyazawa)*.

Typpijatkolannoituksen yhteydessä annetut hivenlannoitteet ovat lisänneet neulasten B- ja Mo-pitoisuuksia nopeasti käytettäessä näitä sisältäviä hivenlannoitteita. Cu-lannoitteet taas eivät ole vaikuttaneet neulasten Cu-toisuuksiin mainittavasti *(Paavilainen ja Pietiläinen)*.

Eräässä koivun *(Betula pendula)* kasvuhäiriötapauksessa syyksi on todettu liiallisen kosteuden indusoima mangaanimyrkytys. Häiriöt hävisivät tai korjaantuivat nopeasti tehdyn täydennysojituksen jälkeen, mikä tuki selitystä *(Raitio)*.

Ruotsissa on kivennäismailla saatu typpilannoituksella aikaan havupuiden kasvuhäiriöitä (diebacks), joka yhdessä kalkituksen kanssa on lisännyt kasvuhäiriöriskiä. Tutkimuksissa männyn neulasten booripitoisuudet erosivat maan pohjois- ja eteläosien välillä.

Vertailukoealoilla neulasten B-pitoisuudet olivat Pohjois-Ruotsissa 7—10 ppm ja

Etelä-Ruotsissa 14—19 ppm. Typpijatkolannoitetuilla koealoilla neulasten booripitoisuudet putosivat 2—7 ppm:ään ja Etelä-Ruotsissa vain 10—15 ppm:ään. Pohjois-Ruotsin jatkolannoitetut koealat olivat kasvuhäiriöisiä. Etelä-Ruotsissa ei kasvuhäiriöitä esiintynyt. Kasvuhäiriöiden primäärisenä syynä pidetään boorin puutetta, mitä myös Ruotsissa havaitut vastaavat maantieteelliset erot makean veden booripitoisuuksista tukevat. Pohjois-Ruotsissa veden booripitoisuus oli 0—4 µg/l ja Etelä-Ruotsissa jopa 128 µg/l *(Aronsson, Möller)*. Lisäksi kasveille käyttökelpoinen boori (tavallisesti alle 5 % totaalimäärästä) voi muuttua vaikeasti saatavaan muotoon kuivuuden, kalkituksen tai typpilannoituksen johdosta. Kohonnut pH ja sitä seuraava boorin saostuminen Al- ja Fe-yhdisteiden kanssa näyttää olevan yksi päätekijöistä boorin fiksoitumisessa maaperään *(Wikner)*.

Saksassa tunnetaan kivennäismaalla männyllä typellä aikaansaatu fosforin ja magnesiumin puute, joka on saatu ehkäistyksi antamalla typen kanssa PKMg-lannoitus. Kuusella on akuutin magnesiumin puutteen havaittu liittyvän neulasten alhaisiin Ca-pitoisuuksiin, mutta myös hyvään N- ja P-tilaan. Hapansateiden katsotaan vaikuttavan tähän ravinne-epätasapainohäiriöön siten, että sade lisää typpeä systeemiin, mutta huuhtoo kalsiumia ja magnesiumia neulasista ja/tai maaperästä *(Rehfuess ym.)*

Männyn kasvuhäiriön ravinnefysiologisissa tutkimuksissa on kasvuhäiriöalueen puiden silmuissa voitu osoittaa pentoosifosfaatti-tiehen kuuluvat 6-P-glukonaattidehydrogenaasientsyymin kohonnutta aktiivisuutta boorin puutostiloissa. Entsyymin aktiivisuus oli korkea koko puiden lepokauden ajan. Suurimmillaan se oli keväällä ennen silmujen puhkeamista. Silmu-uutteisiin lisätyllä boorilla voitiin entsyymin aktiivisuutta säädellä *(Pietiläinen)*.

Erääksi kasvuhäiriön hypoteettiseksi syyksi esitettiin luonnon sähkövaraukset ja niiden indusoimana tapahtuva voimakas typen yhteyttäminen. Lisäksi vahva sähkövirta voi syksyllä lisätä proteiinisynteesiä ja täten keskeyttää talveentumisprosessin. Seurauksena on pakkasvaurioita seuraavana kesänä *(Aurela ja Punkkinen)*.

Australialaiset tutkimukset käsittelivät runsaalla typpilannoituksella aikaansaatua kuparinpuutosta radiata-männyllä, joka voitiin ehkäistä standardilannoituksella — N-P-Cu-Zn-Mo *(Woods)* sekä mangaanin ja raudan puutetapauksia kalkkimailla, jotka voitiin parantaa antamalla vastaavia hivenlannoitteita sulfaatteina *(Ruiter)*.

Istunto 5. Kasvuhäiriön torjunta ja parantaminen

Kasvuhäiriön torjuntaa koskevissa tutkimuksissa ollaan vasta alkuvaiheessa. Suomessa tosin on perustettu hivenkokeita kasvuhäiriöalueille tai kasvihuoneissa vuodesta 1950 yli 150 kpl, mutta kokeista vain pieni osa on viittä vuotta vanhempia. Kokeissa lannoiteboraatti on antanut männyllä parhaat tulokset. Lannoiteboraatti on eräissä tapauksissa vähentänyt kasvuhäiriöitä, parantanut pituuskasvua ja aina lisännyt neulasten booripitoisuuksia. Kuparilannoitteilla on havaittu olevan paikoittain vaikutusta kasvuun. Hyväksi kuparilannoitteeksi on osoittautunut kuparioksidi (CuO). Mangaani-($MsSO_4$) ja sinkkilannoituksella ($ZnSO_4$) tulokset ovat olleet yleensä merkityksettömiä.

Eräissä tapauksissa on havaittu lisäksi negatiivista CuB-interaktiota, joka on voitu estää kalkituksella. Nykyään katsotaan Suomessa boorilannoituksen olevan kannattavaa kaikilla turvemailla. Käytännön lannoitustoiminnassa Suomessa käytettävä suometsien PK-lannos sisältää booria 0,2 % *(Veijalainen)*.

Puuntuhkalannoitus (5000 kg/ha) on antanut kasvuhäiriön torjunnassa parhaat tulokset. Puuntuhka sisältää P, K, Ca, Mg ja useita hivenravinteita. Tuhkalannoituksen vaikutus on nähtävissä neulasistossa ja kasvussa noin 2—4 vuoden kuluttua lannoituksesta. Kasvuhäiriöt samoinkuin sienitaudit on saatu häviämään osassa tutkituista kokeista. Turvemaiden hivenlannoituksella ei näytä olevan vaikutusta puihin mikäli pääravinteiden puute on voimakas, siksi hivenlannoitus tulisi antaa pääravinnelannoituksen yhteydessä tai jälkeen *(Veijalainen)*.

Norjassa turvemaiden puiden kasvuhäiriöitä on voitu ehkäistä booraksilla. Kasvuhäiriöiden torjunnassa suositellaan siellä käytettäväksi yhdistelmälannoitetta, jossa pääravinteiden (N, P, K) lisäksi on booria 1,5—2,0 kg B/ha *(Braekke)*. Ruotsissa booria on lisätty kivennäismailla käytttyyn typpilannoitteeseen 1—2,5 kg B/ha. *(Aronsson, Möller)*.

Italiassa taimien kasvuhäiriöitä on voitu välttää huomioimalla rodulliset ominaisuudet, oikea istutusmateriaali ja ajankohta *(Quaglino)*. Puolassa kuivuuden aiheuttamia kasvuhäiriöitä on voitu välttää levittämällä 400 m^3 männyn kuorta hehtaarille *(Kowalkowski ja Sytek)*.

Retkeily

Leivonmäen Kivisuolle suuntautuneen retken aikana tutustuttiin männyn kasvuhäiriön eri kehitysvaiheisiin, kasvuhäiriön torjuntakokeisiin sekä Metsäntutkimuslaitoksen yli 20 vuotta sitten perustamiin laajoihin lannoituskoesarjoihin. Kentällä esitetyt tulokset osoittivat, että oikeaan aikaan ja oikeassa paikassa suoritetulla lannoituksella voidaan saada puu kasvamaan turvemailla hyvin ja virheettömästi. Varsinkin liian hätiköidyllä jatkolannoituksella voidaan saada aikaan pahoja virheitä. Toisaalta Kivisuon kokeet osoittivat, ettei pitkälle kehittynyttä kasvuhäiriötä voida pysäyttää edes tuhkalannoituksella. Kasvuhäiriön torjuntaan tulisikin ryhtyä heti, kun ensimmäiset oireet ilmaantuvat.

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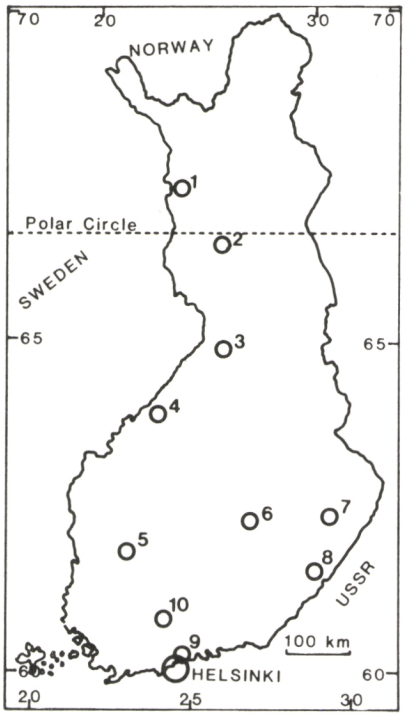
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9 Ruotsinkylä
10 Ojajoki

FACTS ABOUT FINLAND

Total land area: 304 642 km^2 of which 60—70 per cent is forest land.

Mean temperature, °C:	Helsinki	Joensuu	Rovaniemi
January	-6,8	-10,2	-11,0
July	17,1	17,1	15,3
annual	4,4	2,9	0,8
Thermal winter (mean temp. < 0°C):	20.11.—4.4.	5.11.—10.4.	18.10.—21.4.

Most common tree species: Pinus sylvestris, Picea abies, Betula pendula, Betula pubescens

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