METSÄNTUTKIMUSLAITOKSEN TIEDONANTOJA 849
The Finnish Forest Research Institute, Research Papers 849



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Marja-Liisa Juntunen

SUONENJOEN TUTKIMUSASEMA
SUONENJOKI RESEARCH STATION

METLA

**The Finnish Forest Research Institute, Research Papers 849 –**
**METSÄNTUTKIMUSLAITOKSEN TIEDONANTOJA 849, 2002**

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ACADEMIC DISSERTATION
To be presented, with the permission of the Faculty of Natural and Environmental Sciences of the University of Kuopio, for public discussion in Auditorium L.23, Snellmania building, University of Kuopio, on 14 June 2002 at 12 noon.

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Cover photo: Three months old Norway spruce seedlings
in a greenhouse of Suonenjoki nursery
(Photographed by Erkki Oksanen)

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ISBN 951-40-1829-X

Gummerus Kirjapaino Oy
Saarijärvi 2002

# Summary

**Juntunen, M.-L.** Environmental impact of fertilizers and pesticides used in Finnish forest nurseries. Metsäntutkimuslaitoksen tiedonantoja 849 – The Finnish Forest Research Institute, Research papers 849. 58 p. ISBN 951-40-1829-X.



The risk of environmental contamination caused by forest nurseries is poorly known, although ground water pollution and eutrophication of surface waters due to agricultural practices have been reported worldwide. Forest nurseries could, at least, cause local risks because some of them are situated on areas where ground water reservoirs form and/or near lakes and rivers. The objective of this research was to increase our knowledge about the environmental impact of forest seedling production and to find methods to minimize this impact.

In this work, information about the actual systems and practices used by Finnish forest nurseries to grow seedlings and data on the use of fertilizers and pesticides were gathered in 1996 in a large questionnaire-based survey. The leaching of nitrogen (N), phosphorus (P) and four pesticides, (alpha-)cypermethrin, chlorothalonil, triadimefon and propiconazole, from peat growing medium in containers was measured in commercial seedling production of Scots pine, Norway spruce and silver birch. N and P leaching and uptake by container birch seedlings was also measured when slow-release fertilizers were used in the commercial growing of seedlings.

In 1996 the nurseries surveyed here produced about 104 million container and 15 million bareroot seedlings, which made up 85% of the total Finnish seedling production. Over 90% of all container Scots pine and silver birch and 43% of Norway spruce seedlings were delivered for planting as one-year-old seedlings, and the rest mostly as two-year-old seedlings. The main bareroot stock type was four-year-old spruce. About half of the total amount of fertilizers and pesticides, 175 000 and 662 kilograms (a.i.), respectively, was used in bareroot seedling production and the other half in container seedling production.

On the questionnaire the use of fertilizers and pesticides was asked in two ways: total use during the 1996 growing season according to annual inventories and use in growing certain seedling lots. These two approaches gave different results. Apparently, on the basis of values obtained from lot-based information, it is not possible to calculate the total use.

According to the annual inventories, nurseries used, per shipped seedling, about eight times more N, five times more P and four times more pesticides for growing a bareroot seedling than for a container seedling. The mean annual applications of N and P were about 180 kg $ha^{-1}$ and 90 kg $ha^{-1}$, respectively, for container stock and 130 kg N $ha^{-1}$ and 40 kg P $ha^{-1}$, respectively, for bareroot stock, assuming that the total amount of nutrients was applied to the whole production area. The nurseries applied, on average, 1.7 kg pesticides (a.i) $ha^{-1}$ annually, although the amount varied considerably between nurseries. On fields of bareroot seedlings the nurseries applied, on average, 3.9 kg pesticides (a.i.) $ha^{-1}$.

For growing seedlings in containers, most of the nurseries used special peat for tree seedlings, into which fertilizer and magnesium-rich lime had been premixed by the supplier. On the basis of lot-based information, the amounts of N and P applied in fertigation varied greatly between nurseries; the nursery with the greatest use of fertilizers applied about six times more N and P than the nursery with the smallest use of fertilizers. Often there were one or two nurseries whose fertilizer use differed from that of the majority. Tree species had little influence on the mean amounts of nutrients premixed and fertigated per unit area; but because of the different growing densities, the mean amounts of N applied per seedling grown in a container were 147, 46 and 37 mg for one-year-old birch, spruce and pine, respectively. For birch and pine production, the mean amounts of pesticide (a.i.) per grown seedling were almost the same, 1.6 and 1.7 mg, respectively; for production of spruce seedlings the comparable values were less than 0.5 mg. The highest mean amounts of pesticides were applied annually to pine seedlings (9.5 kg $ha^{-1}$) and the lowest to spruce seedlings (0.9 kg $ha^{-1}$).

Based on the leaching studies, the amounts of N and P leached annually were 19 to 41 and 11 to 56 kg $ha^{-1}$, respectively. Depending on tree species, 11 to 19% of the applied N was recovered in leachates and 15 to 63% in seedlings, while 16 to 64% of the applied P was found in leachates and 5 to 31% in seedlings. Only part of the applied N and P not found in seedlings leached from the growing medium, which means that only the potential risk of leaching can be estimated by determining the nutrient content of the seedlings. The amounts of N and P fertigated outside the container trays could, however, increase the total load of N and P per unit area.

In Finnish nurseries, birch container trays are separated and placed about 20 cm apart about one month after sowing, which means that at maximum about half of the irrigation (fertigation) water falls outside container trays. Based on the leaching study, the premixing of slow-release fertilizers into peat growing medium decreased the total N and P load per hectare, since no nutrients were fertigated outside container trays. On the other hand, the use of slow-release fertilizers instead of fertigation did not diminish the leaching of N and P from containers into the ground. The leaching of N was greatest at the beginning of the growing period. The slow rate of release means, however, that the amounts of slow-release fertilizer premixed into the peat must be large enough to guarantee the desired growth of birch seedlings; and therefore the efficiency of N and P use by seedlings was low, 29 to 45% and 15 to 33%, respectively.

In pine production almost 30% of the applied propiconazole but less than 1% of the applied chlorothalonil and in birch production less than 5% of applied triadimefon and (alpha-)cypermethrin leached from the peat medium. In addition to processes (volatilization, degradation, adsorption, leaching) on needles and shoots, adsorption to peat and degradation in the peat medium are obvious reasons for the small amounts of pesticides leached. More studies with different pesticides used on the different growing media are needed before it will be possible to say with certainty whether the container production of forest seedlings has decreased the risk of environmental contamination due to pesticides.

An average Finnish nursery uses much smaller amounts of nutrients and pesticides to grow the same number of seedlings at the beginning of the 2000s than at the beginning of the 1980s. Although the smaller use of fertilizers and pesticides already decreases the possible risk of environmental contamination, evaluation of production systems and methods could help nurseries to develop growing practices that would further decrease the nutrient and pesticide load on the environment. Water management is an important means of controlling contamination of the environment. Practices that increase the efficiency of irrigation and efficiency of nutrient use by seedlings obviously decrease the environmental load. Excluding the influence of rain by covering outdoor areas with movable roofs could be a solution worth studying in Fennoscandian conditions. Making changes in nursery practices may increase production costs, but at the same time it can be assumed that many of these measures could improve the outplanting performance of seedlings.

**Keywords:** agricultural pollution, fungicide, controlled-release fertilizer, groundwater, herbicide, insecticide, nitrogen, nutrient uptake, phosphorus, seedling, slow-release fertilizer, survey study

**Publisher:** The Finnish Forest Research Institute, Suonenjoki Research Station.
Accepted by Kari Mielikäinen, Research Director.

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# Preface

This study was carried out at Suonenjoki Research Station and Research Nursery and Vantaa Research Centre of the Finnish Forest Research Institute and at North Savo Regional Envionment Centre. I am grateful for the excellent working facilities provided by Suonenjoki Research Station and Nursery. This study was supported by the Regional Council of Pohjois-Savo, the Centre of Expertise for Wood Technology and Forestry, the Academy of Finland, and the foundations Metsämiesten Säätiö and Niemi Säätiö, all of which are gratefully acknowledged. I wish to express my sincere thanks to the personnel of the forest nurseries, who made part of this study possible by answering the extensive questionnaire.

I am most grateful to my supervisors, Dr. Helvi Heinonen-Tanski and Dr. Heikki Smolander, Head of the Suonenjoki Research Station. Helvi, I thank you for critical reading of my manuscripts. Heikki, I appreciate very much your support and encouragement. My warmest thanks to my co-authors Taina Hammar, M.Sc., Dr. Veikko Kitunen and Dr. Risto Rikala. Risto, I would "have lost the steering of my boat" without your kind guidance and valuable advice throughout the course of this work. Veikko, the discussions about pesticide chemistry were very helpful. Taina, it was pleasant and fruitful to co-operate with you. I express my gratitude to Dr. Arja Lilja, Dr. Jaana Luoranen and Dr. Marja Poteri for their valuable comments on and suggestions about the manuscripts and for encouraging me in my work. I wish to thank Professor Leena Finér and Dr. Mats Hannerz for constructive criticism and careful work in reviewing the manuscript.

I thank Dr. Joann von Weissenberg warmly for revising the English language of the thesis and the included articles, Mr. Seppo Oja for the text layout, and Raili Voipio, M.Sc. and Mr. Pekka Voipio for help with figures, and Mr. Erkki Oksanen and Mr. Pekka Voipio for taking the photos.

I thank my colleagues and friends at Suonenjoki Research Station and Nursery for the help and support – almost every one of you has, in one way or another, contributed to this work. I would like to express my special thanks to Mr. Pauli Karppinen, Mr. Jukka Laitinen, Mikko Maukonen, M.Sc., Sirpa Metsärinne, M.Sc., and Anna-Maria Veijalainen, M.Sc. for technical assistance.

Finally, I thank my husband Eero and my children Hanna and Antti for their existence and their love.

Taipalsaari, April 2002

*Marja-Liisa Juntunen*

# Contents

# Original articles

This thesis is a summary based on the following articles, which will be referred to in the text by their Roman numerals. Additional data are also presented.

**I** Juntunen, M.-L. and Rikala, R. 2001. Fertilization practice in Finnish forest nurseries from the standpoint of environmental impact. New Forests 21(2): 141–158.

**II** Juntunen, M.-L. 2001. Use of pesticides in Finnish forest nurseries in 1996. Silva Fennica 35(2): 147–157.

**III** Juntunen, M.-L., Hammar, T. and Rikala, R. 2002. Leaching of nitrogen and phosphorus during production of forest seedlings in containers. Journal of Environmental Quality (accepted).

**IV** Juntunen, M.-L., Hammar, T. and Rikala, R. 2002. Nitrogen and phosphorus leaching and uptake by container birch seedlings (*Betula pendula* Roth) grown in three different fertilizations. New Forests (accepted).

**V** Juntunen, M.-L. and Kitunen, V. 2002. Leaching of propiconazole and chlorothalonil during production of *Pinus sylvestris* seedlings in containers. Manuscript (submitted).

# Abbreviations

| | |
|---|---|
| a.i. | active ingredient |
| EC | electrical conductivity |
| N | nitrogen |
| $NO_3$-N | nitrate nitrogen |
| $NH_4$-N | ammonium nitrogen |
| P | phosphorus |
| $PO_4$-P | phosphate phosphorus |
| PF | fertilizer treatment, where half of the amount of nutrients was premixed into the peat medium and the other half was applied as liquid (=fertigated) (IV) |
| P-N | fertilizer treatment, where fertilizer ST and fertilizer NutricoteT70 were premixed into peat (IV) |
| P-VN | fertilizer treatment, where fertilizer "Vital Nursery" was premixed into peat (IV) |

# 1 Introduction

Ground water pollution and eutrophication of surface waters due to agricultural practices has been reported worldwide. Still, the risk posed by production of forest tree seedlings, even it is widespread, is poorly known. Although the total use of fertilizers and pesticides in forest nursery production is small compared to that in agriculture and horticulture, there can be at least local risks because some nurseries are situated on areas where ground water reservoirs form and/or near lakes and rivers. Mälkki et al. (1988) reported that production of bareroot seedlings may contaminate ground water with nitrogen (N) compounds from fertilizers. Seedling production is part of forest industry, and therefore knowledge of the environmental impact of nurseries is also needed, for example, in life cycle analyses of wood products (Aldentun 2002).

In 1999, Finnish forest nurseries produced 145 million seedlings, of which 122 million were grown in containers and 23 million were bareroot seedlings. On a percentage basis, Norway spruce (*Picea abies* Karst.) accounted for 48% of the total, Scots pine (*Pinus silvestris* L.) 40%, silver birch (*Betula pendula* Roth) 9%, downy birch (*B. pubescens* Ehrh.) 1% and lodgepole pine (*Pinus contorta* Doug. ex Loud.), Siberian larch (*Larix sibirica* Ledeb.) and other tree species 3% (Västilä and Herrala-Ylinen 2000).

The production of forest seedlings in Finland has changed greatly in the last 40 years. During the 1960s, seedling production increased from 50 to 250 million seedlings. New nurseries were established on light sandy forest soils instead of on farmlands, and peat and chemical fertilizers were used for soil improvement and a source of nutrients instead of livestock manure and compost. There was, however, great variation in fertilization practices between nurseries (Rikala and Westman 1979).

During the 1980s the introduction of plastic greenhouses with automated irrigation, fertilization and temperature-regulating devices continued. Concurrently, container seedling production replaced bareroot production. In the late 1980s about 70% of all seedlings were produced in containers, whereas in the early 1980s only about 30% of the pine seedlings had been grown in containers. New nursery technology and systems of production decreased the growing time for nursery seedlings from four years to one – two years. In spite of the short growing time needed to produce seedlings, nurseries still have problems with pests (Uotila 1995, Lilja et al. 1997).

During the 1990s, the annual seedling production in Finland decreased to about 150 million seedlings. This decrease was mainly

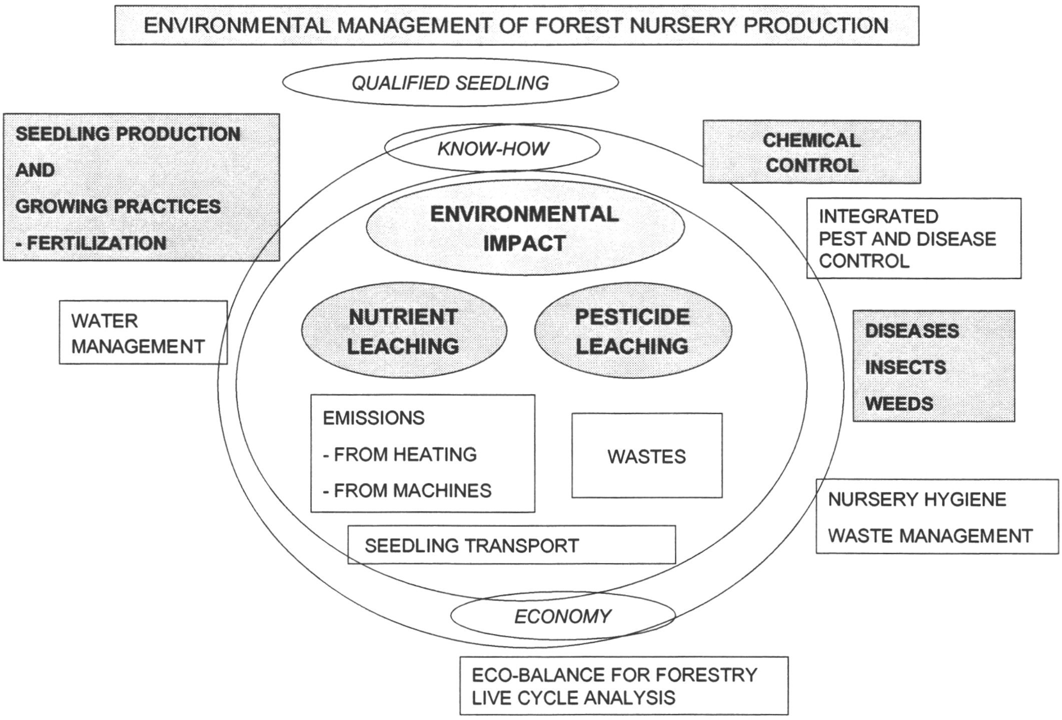


**Figure 1.** Environmental impact of forest tree nurseries and some influencing factors.

in pine production and was due to natural regeneration and artificial seeding. The number of small family-owned nurseries increased at the end of the 1980s and at the beginning of the 1990s, to about 60 in 1996 (Mäkinen et al. 1999). At end of the 1990s the number of enterprise-owned nurseries decreased. In 1996, there were eight nursery enterprises, which owned 35 nurseries; but in the year 2000 only six enterprises and 25 nurseries remained. The enterprise-owned nurseries are, however, producing 85 to 90% of the total number of seedlings.

Forest seedling production could be seen from at least two environmental standpoints: nurseries as possible point sources of harmful chemicals and as part of artificial regeneration in life cycle analyses of wood products (Figure 1). If nurseries are looked upon as point sources of agricultural pollution, the harmful substances of importance for human health and the environment are nitrogen (N) and phosphorus (P) compounds as well as pesticides and their metabolites (Landis et al. 1991). The handling of bio wastes could indirectly influence the pollution potential of nurseries (Figure 1). For example, effective waste management and good nursery hygiene could decrease the risk of diseases and the need for chemical control. Aldentun (2002) has shown in life cycle inventory studies that, of the various emissions from forest nurseries in Sweden, greenhouse heating was the activity that gave rise to the highest level of $CO_2$ emissions. Due to the lack of reliable data concerning the use and leaching of pesticides and nutrients in forest nurseries, Aldentun (2002) could not include these parameters in her life cycle inventory.

Not only in Finland but also in the other Fennoscandian countries and in Canada, the change from bareroot production to container seedling production has probably influenced the risk of environmental contamination by forest nurseries. The production of bareroot seedlings is similar to agricultural production, and knowledge about the impact of agricultural operations can be used in evaluation of bareroot production. Production of container seedlings, on the other hand, is more like horticultural production. However, there are some differences, for example, forest seedlings are grown in small pots, 40 to 300 ml in volume, while most horticultural crops are grown in large, individual pots, one to five litres in volume. The individual pots, in forest nursery terminology often referred to as containers, are usually produced in aggregates called trays (Landis et al. 1990). On the whole, there are very few data for use in risk analyses of possible harmful effects of container seedling production or data for life cycle analyses of wood products, and therefore this thesis concentrates on container seedling production.

## 1.1 Water management and the environment

Water management is an important factor for controlling the discharge of nutrients and pesticides to surface and ground waters, because water acts as a carrier of N and P compounds and pesticides (Figure 2). In container production of forest seedlings most fertilizers are applied in liquid form through an irrigation system (=fertigated) (Landis et al. 1989a, Dumroese et al. 1995), and therefore irrigation and fertilizer efficiencies are directly related (Bilderback 2001). In addition, pesticides are usually applied in a water carrier through the irrigation system (Landis et al. 1989a).

In container production, seedlings are raised in greenhouses either during part of the growing season or in some cases throughout the whole growing season. In greenhouses, only irrigation influences the amounts of discharged water, but in outdoor areas, rain can have a great impact on amounts of discharged water. Here the term, "discharged water", includes both surface runoff and percolated water. In the production of container seedlings, the percolated water could be collected in two phases: first, the water that percolates from the growing medium and second, the water that percolates through the soil profiles to the ground water.

### *1.1.1 Irrigation systems and methods*

The amount of discharged water depends on the efficiency of irrigation. According to Bilderback (2001), irrigation efficiency can be related to three aspects of water application. First, the irrigation system, the design of irrigation systems and the layout of container trays influence the amount of water that falls outside the seedlings. Forest nurseries use mostly overhead irrigation systems, either mobile irrigation booms or fixed irrigation systems (Landis et al. 1989a). Dumroese et al. (1995) determined that in their nursery with a mobile boom system, 12.5% of the irrigation water fell outside the seedling trays. Otherwise, very little information has been published on the irrigation efficiency of application systems used in forest nurseries (Landis et al. 1989a). The second aspect influencing the irrigation efficiency is the uniformity of application, which also depends on the irrigation system used.

Third, the method of irrigation influences the amount of water that percolates from the growing medium. Lamack and Niemiera (1993) spoke about water application efficiency, which actually measures the amount of water retained within the growing medium compared to the amount of water applied. Irrigation frequency, for example, has an impact on the efficiency of water application. Lamack and Niemiera (1993) and Fare et al. (1994) found that the amount of water percolated from containers (= leachate) was smaller when the total volume of water applied to plants daily was divided into two or three spraying cycles instead of only one cycle. Karam and Niemiera (1994) have shown that, in addition to irrigation frequency, the water content of the substrate before application and the amount of water applied influence the water application efficiency, which is to be expected. In their experiments, the nearer to the container capacity the water content of the pine bark substrate was before irrigation the greater were the amounts of leachate.

### *1.1.2 Monitoring of water discharge*

The discharge of water can be monitored on different scales (Figure 2). We can examine either on the nursery scale or, in container production, on the scale of one greenhouse or seedling lot; and the smallest unit could be one container tray or an individual container. For example, we can collect water from different surface runoff points. Obviously, with this kind of monitoring on the nursery scale it is possible to determine whether nutrients and pesticides are leaving the nursery. On the basis of this monitoring, it could be, however, difficult to measure the amounts of water and harmful substances

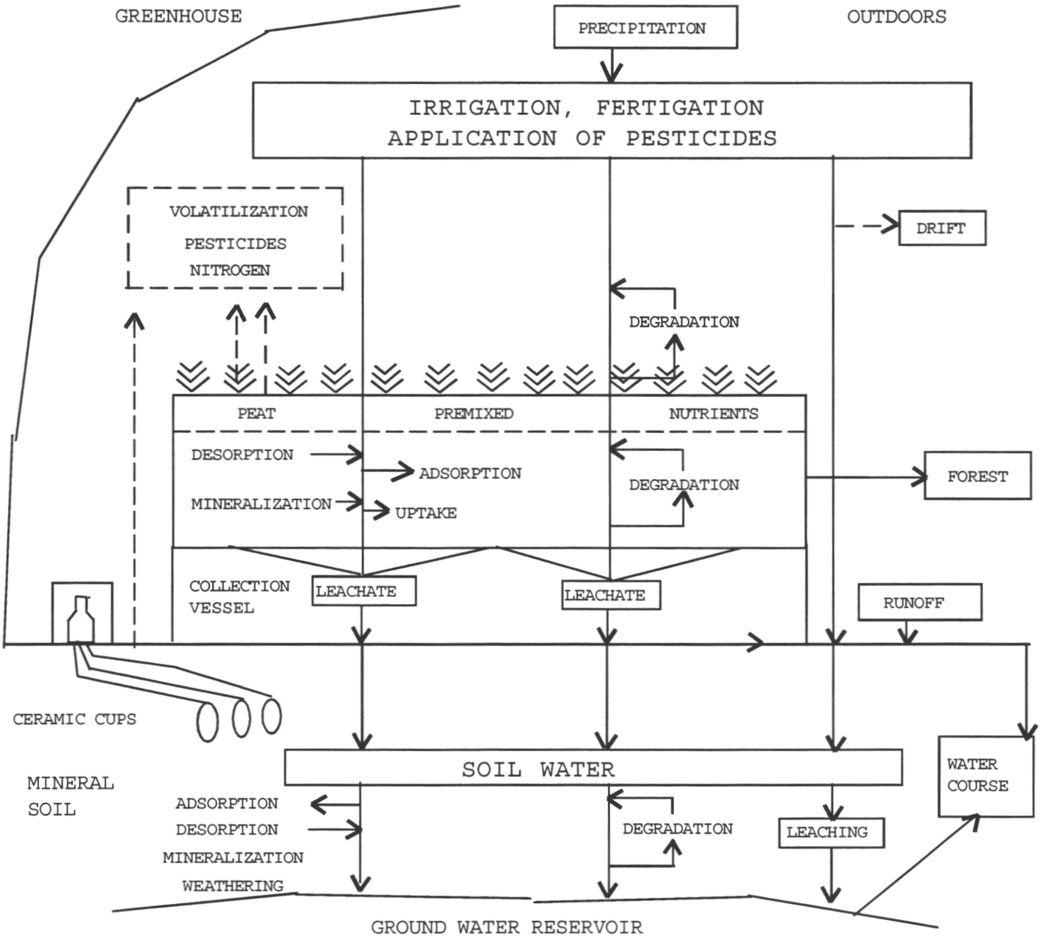


**Figure 2.** Schematic presentation of the flux of water, nutrients and pesticides in container production of forest seedlings.

leaving the nursery and to find differences between point sources within the nursery. The seedling lot or the container tray scale could help to ascertain the amounts and the differences between sources so that control measures could be targeted correctly.

## 1.2 Nutrients and the environment

### *1.2.1 Possible risks*

Use of chemical fertilizers has increased the amount of N and P transferred from agricultural fields to surface and ground waters (Vitousek et al. 1997, Tiessen 1996). The excess of P, in particular, but also of N in the surface water, has accelerated the eutrophication of these waters (Kauppi et al. 1993). Eutrophication of lakes, rivers and coastal waters is the main environmental problem caused by agriculture in Finland, especially in the intensively cultivated region of southern and western Finland. Small shallow lakes, typical in agricultural regions, are most sensitive to eutrophication (Kauppi et al. 1993).

In the European Union (EU) $NO_3$-N-levels greater than 11.3 mg $l^{-1}$ in drinking water are considered unsafe for humans (European Community 1998). High nitrate concentrations in drinking water could affect, in particular, the health of infants. In the digestive tracts of infants micro-organisms reduce nitrate to nitrite, which is absorbed into the bloodstream and impairs the ability of hemoglobin to transport oxygen, producing a condition called methemoglobinemia.

### *1.2.2 Fertilization practices*

In container production of forest seedlings, most fertilizers are applied in liquid form through an irrigation system (=fertigated) (Landis et al. 1989a, Dumroese et al. 1995), and therefore the efficiency depends on the irrigation system used. Solid fertilizers are applied to some extent, mostly premixed into growing medium. Because of the small top opening of the containers, top dressing of solid fertilizers is seldom used (Landis et al. 1989a).

The fertilization practices of forest nurseries in different parts of the world have been reviewed (Landis et al. 1989a, Donald 1991). These reviews consider the use of nutrients from the standpoint of the seedlings but not that of the environment, and the total rates of nutrients per unit area or per seedling have seldom been given for the whole growing season. The most recent Finnish information about use of fertilizers in forest nurseries is from the end of the 1970s (Rikala and Westman 1979).

Both fertilization system and method could influence the risk of contaminating the environment. If the application equipment used applies a large proportion of fertilizers directly into the ground alongside and between the seedling containers, the nutrients applied outside seedlings could produce a greater load on the environment than the nutrients leached from the growing medium. The fertilization method could influence the efficiency of nutrient use by seedlings. For example, Timmer (1997) showed that, by applying the nutrients in exponentially increasing additions instead of at a constant rate of addition, it is possible to increase the efficiency of nutrient use by seedlings and decrease the amount of nutrients applied.

The fertilization method could also influence the risk of contamination so that nutrients could leach from the growing medium before the seedlings take them up. The risk for leaching is obvious, if water-soluble fertilizers are premixed into the growing medium. The need to keep the surface of the growing medium wet in order to promote seed germination may lead to overirrigation and leaching of nutrients. During the first growing weeks the high nutrient content of the growing medium and the low uptake of nutrients by seedlings may cause leaching.

The nutrient content of the growing medium can be high, especially when slow-release fertilizers, also known as controlled-release fertilizers, are premixed into peat. There are two basic types of slow-release nitrogen fertilizers: coated fertilizers and fertilizers with sparingly soluble nitrogen compounds (Oertli 1980, Shaviv and Mikkelsen 1993, McNabb and Heser 1997, Trenkel 1997). In coated fertilizers the water-soluble nutrients are surrounded by a diffusion barrier, i.e. by a coating. The coating can be made from sulfur and/or from different polymer materials, and the rate of nutrient release can be manipulated by changing the coating thickness and composition. The nutrients are released slowly by diffusion or mass flow through the barrier, and therefore temperature also affects the release of nutrients.

There are different types of fertilizers with sparingly soluble nitrogen compounds (Oertli 1980, McNabb and Heser 1997), such as methylene urea and isobutyraldehyde. Depending on the compound, nitrogen is released by hydrolysis and/or microbial degradation. The environmental factors that control microbial activity also control the decomposition of these compounds and nitrogen release, including temperature, moisture, pH and aeration status.

The use of slow-release fertilizers was not very common in North American nurseries in the late 1980s (Landis et al. 1989a), but there has been some interest in their use during recent years (McNabb and Heser 1997). The reasons for their limited use might be the incomplete regulation of nutrient release, the uneven distribution of premixed fertilizers in small capacity containers and the high price of such products.

### *1.2.3 Efficiency of nutrient use by seedlings*

The influence of fertilization on seedling quality has been studied from different points of view (Rikala 1997), such as fertilization methods (Timmer 1997), effects of fertilization on frost hardening (Colombo et al. 2001), and the outplanting performance of seedlings (van den Driessche 1991). Very little attention has been paid to the efficiency of fertilization, i.e. what proportion of the applied amount could be recovered in seedlings, perhaps because the fertilization costs are marginal (South and Zwolinski 1996). On the basis of efficiency, it would be possible to estimate the nutrient losses from a nursery. If the nutrient content of the growing medium is also monitored, the estimate would be more precise.

Care is needed in these calculations, because the efficiency could be seen from the standpoint of the seedling and from the standpoint of production. When the efficiency is examined from the standpoint of the seedling, we measure how effectively a seedling has used the nutrients applied to it. On the other hand, when we look upon efficiency from the standpoint of production, we calculate how effectively the shipped crop has used the nutrients applied. We have to take into consideration, for example, the amounts of nutrients applied outside the seedlings. Obviously the number of shipped seedlings is smaller than the number of seedlings grown, which also influences the use of resources.

### *1.2.4 Studies of nutrient discharge*

There are a few studies of nutrient discharge from forest nurseries. In Finland, Mälkki et al. (1988) concluded that production of bareroot tree seedlings may contaminate ground water with N compounds from fertilizers. In an area where bareroot seedlings were produced, they measured nitrogen (N) concentrations of 9–35 mg $l^{-1}$ in monolith lysimeter water. Dumroese et al. (1991,1995) have published results concerning the discharge of water and N in the production of container conifer seedlings in one nursery. According to their results, the amounts of N discharged were large, 32 to 70% of the amount applied.

## 1.3 Pesticides and the environment

### *1.3.1 Possible risks*

Pesticides are a heterogeneous group of chemicals, and their risks to human health and environment vary greatly. According to Gallivan et al. (2001), the health and environmental risk is a function of the toxicity of the pesticide and the level of exposure. Assessment of the risk caused by a pesticide is a process with several steps, beginning with an appraisal of toxicity and exposure and concluding with characterization of the risk. Toxicological characterization is commonly based on laboratory studies. Exposure concentrations may be either estimated or measured, based on the amounts and manner in which chemical is used, the physico-chemical properties of the pesticide, and data from laboratory and field experiments. For example, in the EU the guideline limit for an individual pesticide in drinking water is 0.1 $\mu g\ l^{-1}$ and for the total sum of all pesticides it is 0.5 $\mu g\ l^{-1}$ (European Community 1998). Risk characterization defines the likelihood that humans or wildlife will be exposed to hazardous concentrations.

Different systems of risk assessment, from descriptive to holistic and comprehensive assessment models, have been developed for assessing the relative environmental impacts of pesticides (Levitan et al. 1995). Levitan et al. (1995) concluded, however, that at the level of use the problem is "How to strike a balance between the advantages of the ease of use of simpler systems with the information-richness of more complex systems that may be prohibitively difficult to use".

### *1.3.2 Occurrence of pests*

Pests are biological agents responsible for causing diseases and growth losses. The standard agents include fungi, insects, mites and nematodes as well as less known pests such as vascular weeds, liverworts, moss, algae and snails. Nurseries have had problems with different pests (Sutherland and Glover 1991, South 1995, Uotila 1995, Lindelöw 1996, Stenström 1996, Lilja et al. 1997, Juntunen 2000). In container nurseries, the moderate temperatures, high humidity, low wind velocities and high growing densities of seedlings are ideal for many diseases, especially for those on shoots (Landis et al. 1989b, Sutherland et al. 1989). Twelve diseases (if the root dieback of Norway spruce and Scots pine are considered to be separate diseases) caused seedling losses in Finnish nurseries in 1996 (Juntunen 2000). Scots pine, in particular, has many nursery diseases (Lilja 1986).

Among the enterprise-owned nurseries, the disease situation was worst in one nursery where, according to the report of this nursery, 11 different diseases occurred. In six nurseries, 5–6 diseases caused losses, 3–4 diseases were reported in eight nurseries while four nurseries listed the occurrence of 1–2 diseases (Juntunen 2000). The same diseases also occurred in Swedish nurseries in the early 1990s (Stenström 1996). In Sweden, grey mold (*Botrytis cinerea* Pers. ex Nocca and Balb) was the most common fungal pest, but *Lophodermium* needle cast (*Lophodermium seditiosum* Minter, Staley and Millar) has constituted the greatest problem, while the stem lesions of birch (*Phytophthora cactorum* (Leb. and Cohn) Schr.) and root dieback of Norway spruce (*Ceratobasidium bicorne* J.Erikss. and Ryvarden) were the most common nursery diseases in Finland.

The peat growing medium used in containers is normally free of weed seeds, but the history of nurseries influences the occurrence of weeds. Most weeds arising in container nurseries occur as the result of wind-blown seeds from bareroot or fallow fields (Juntunen 2000). *Senecio vulgaris* L., *Poa annua* L. and *Matrix* sp. have been listed by nurseries as being weeds that are difficult to control (Juntunen 2000). They were particularly troublesome in bareroot fields and also in outdoor container areas. In recent years, Bryophyta, especially liverworts have become much more troublesome in containers (Juntunen 2000).

Aphids were the most common and *Lygus* bugs the next most abundant insect pests in Finnish nurseries during the 1996 growing year (Juntunen 2000).

### *1.3.3 Use of pesticides in forest nurseries*

The Finnish annual statistics on amounts of pesticides sold are not very useful, because it is not possible to separate the amounts sold to forest nurseries from those sold for other purposes. Moreover, pesticide products are very seldom registered for forest nursery use only. In Finland the most recent estimate of pesticide use in forest nurseries was made at the end of the 1970s, when Kangas et al. (1980) estimated that Finnish forest nurseries used at least 18 000 kilograms of pesticides (as active ingredient, a.i.) annually. When the nurseries produced about 190 million shipped seedlings annually at the end of 1970s, the use of pesticides was about 95 kg pesticides (a.i.) per million shipped seedlings.

### *1.3.4 Fate of pesticides in the nursery environment*

The physico-chemical properties of the active ingredient, such as solubility in water, volatility, soil-sorption tendency, persistence and ionization potential, are used to estimate the leaching potential of the active ingredient (Augustijn-Beckers et al. 1994, Tomlin 1997). In addition to the characteristics of the active ingredient, the soil properties and in container production the properties of the growing medium and cultural practices, e.g. the irrigation system and methods, influence the fate of the active ingredient in the nursery environment (Figure 2) (Landis et al. 1991, Torstensson and Stenström 1995, Bergström and Stenström 1998). The fate and mobility of pesticides in soil has often been described by mathematical models, for example, to help assess the risks associated with pesticides (Bergström et al. 1994, Boesten 2000).

Torstensson and Stenström (1990) concluded that in coarse-structured soils, like the soils in the forest nurseries studied, heavy rainfall or irrigation could transport small particles containing adsorbed herbicides into the subsoil. Because of the low content of organic matter and low microbial activity in subsoil, the rate of decomposition will decrease and pesticides will be available longer for downward transport in the soil profile of nurseries. Mälkki et al. (1988) monitored concentrations of atrazine and quintozene – used in the 1980s in Finnish forest nurseries – in monolith lysimeter water beneath a bareroot field and also from ground water near a nursery. Based on their measurements, they concluded that if the thickness of the soil layers between the ground and the ground water reservoirs is over 10 meters, the risk of contamination caused by these pesticides is minimal.

Many aspects of container seedling production, however, differ from those for bareroot seedling production. Most pesticides are sprayed on very densely growing seedlings and only part, depending on the system of application, is sprayed directly onto the ground. There have been only a few studies concerning the leaching of herbicides from media used in container nurseries (Wehtje et al. 1993, Mahnken et al. 1994, Grey et al. 1996). As far as I know, there are no published results either about leaching of fungicides or studies of these aspects in the commercial production of container forest seedlings.

# 2 Aims of the study

The main aim of this study was to survey the environmental impact of forest seedling production by inventorying the use of fertilizers and pesticides in Finnish forest nurseries and by ascertaining how much is leached into the ground in production of container seedlings. This work was done to increase our knowledge about the environmental load of forest seedling production and to discover methods of minimizing.

The work concentrated on the following questions:

## 2.1 Use of fertilizers and pesticides in Finnish forest nurseries (I and II)

In this part of the study the following aspects were described: the use of fertilizers (I) and pesticides (II) in container and bareroot seedling production, methods of fertilization and pesticide applications, and methods used to determine the need for fertilization and irrigation in container seedling production. Here the detailed aim was to calculate and present both area- and seedling-based values for use of nutrients and use of herbicides, fungicides and insecticides in production of container seedlings of different tree species.

## 2.2 Leaching of nutrients and pesticides from the peat growing medium in container seedling production (III, V)

In these studies were investigated: 1) the leaching of N and P from peat medium in containers and the nutrient uptake of seedlings in commercial production of Scots pine, Norway spruce and silver birch in a nursery (III), and 2) the leaching of pesticides, propiconazole and chlorothalonil, from peat growing medium into the ground during commercial production of container Scots pine seedlings (V). The concentrations of chlorothalonil in soil water beneath the container areas were also measured. The leaching of pesticides, triadimefon and (alpha-)cypermethrin, was studied in container birch production; and part of these data are published in this thesis.

## 2.3 Use of slow-release fertilizers in container birch production (IV)

About one month after sowing, birch container trays are separated from each other by 20 cm of free spaces, which causes, at maximum, about half of the fertigation water (nutrients) to fall outside the container trays. By premixing slow-release fertilizers into growing medium, it may be possible to avoid fertigation; therefore the influence of three fertilizer treatments with nutrients in soluble and slow-release form on the leaching of N and P and on nutrient uptake of birch seedlings was investigated in a leaching study. The N and $PO_4$-P concentrations in soil water beneath the container area were also measured. On the basis of leaching results, the influence of these treatments on the total N and P load in container birch production could be estimated.

# 3 Materials and methods

## 3.1 Questionnaire-based survey

### *3.1.1 Content of questionnaire*

Information about the actual systems and practices used by Finnish forest nurseries to grow seedlings was gathered in a questionnaire-based survey (I and II). The questionnaire was divided into three parts. The first part dealt with the number of seedlings grown and with the areas, equipment and growing methods (I). Nurseries were also asked to report, according to the specific brand of each product, the amounts of fertilizers and pesticides used in 1996 for production of container and bareroot seedlings, and also the amount of pesticides used for open areas without containers, fallow fields and edges. This information was based on the annual inventories of the nurseries.

In the second part of the questionnaire, more detailed questions were asked about cultivation practices and the schedule of the largest container seedling lots, e.g. sowing dates, period in the greenhouse, dates of fertigation and fertilizer doses (g $m^{-2}$) (I), and for pesticides such information as application dates, trademarks of the pesticides used and the doses used per hectare (II). To transform the amount of fertilizers into nutrient doses, the nutrient concentration of fertilizers declared in the specifications of the fertilizer manufacturers were used.

In the third part of the questionnaire the nurseries gave information about disease and insect problems in their nursery during the 1996 growing season (Juntunen 2000).

### *3.1.2 Survey nurseries*

In 1996, in Finland there were eight nursery enterprises, which together owned 35 nurseries (later called enterprise-owned nurseries). The enterprise managers made a collective decision that all enterprises would take part in the survey. However, some managers announced that due to ongoing changes within the enterprises only a part of the nurseries would participate in the survey. Of the 23 nurseries that received the questionnaire, replies were received from 20. In addition to these enterprise-owned nurseries, there were about 60 family-owned nurseries. Of these family nurseries, ten subjectively chosen nurseries were asked to complete the questionnaire and, of those, eight replied. Most of those selected were among the biggest seedling producers of the family-owned nurseries.

The survey covered 83% of the total seedling production for 1996 in Finland (I). The representativeness of the questionnaire was estimated by comparing the number of shipped seedlings given in answers to the questionnaire (119 million) with those reported in the official statistics (144.4 million)(Västilä and Herrala-Ylinen 1998).

During the 1996 growing season, the surveyed nurseries grew about 128 million container seedlings, consisting of 74.5 million Norway spruce, 41.1 million Scots pine, 8.8 million silver birch and 3.8 million other species such as downy birch and Siberian larch (I). Over 90% of the birch and pine, but only 43% of the spruce were shipped out for forest planting as one-year-old stock. The rest of the spruce seedlings produced were delivered for planting at the age of two years. For planting in the spring of 1997, the nurseries produced 15.4 million bareroot seedlings, about 10.8 million spruce, 3.1 million birch and 1.6 million pine. The main bareroot stock type was four-year-old spruce.

### *Enterprise-owned nurseries*

The oldest nursery was founded in 1936 and the newest in 1985. Most of the nurseries, altogether nine, were founded in the 1960s. The nurseries were located in different parts of Finland at 59–66°N latitude (see Rikala 2000). All nurseries grew container seedlings, and twelve of these nurseries also grew bareroot seedlings in their fields. Each nursery produced, on average, 5.7 million shipped seedlings. The range was, however, great: 1.6 to 10.3 million seedlings. The mean size of each enterprise-owned nursery was about 30 hectares, of which about half was used for seedling production. The rest consisted of fallow-fields, yards, roads and edges.

### *Family-owned nurseries*

Two of the family-owned nurseries were founded in the 1960s, the oldest in 1965. The other six nurseries were founded after 1988, the newest in 1992. All nurseries, except for one, were located north of 62 °N. All nurseries grew only container seedlings; and the average seedling production was 0.6 million shipped seedlings, the range being 0.1 to 1.3 million seedlings. One nursery grew all three main tree species (Norway spruce, Scots pine, silver birch); the others concentrated on growing either pine or spruce seedlings.

### *3.1.3 Calculations*

The use of nutrients and pesticides in forest nurseries was calculated either per unit area or per seedling (I and II). The mean area-based values were calculated as nursery averages. Zero values, which meant that pesticides were not used, were not included in the mean values. Thus the per area values can be used to describe the differences between nurseries; and if seedlings were sprayed, the mean value described the real load on the nursery environment associated with the applications.

The area-based values were transformed to seedling-based values with the help of growing densities (I and II). The mean seedling-based values were calculated weighted by the numbers of seedlings produced by nurseries; and the zero values were included because, if these values are used in life cycle analyses (Aldentun 2002), this is related to information about the total production of forest seedlings.

## 3.2 Leaching studies

The leaching of N and P and four pesticides from peat growing medium in containers was monitored in commercial forest seedling production at Suonenjoki nursery in 1995–1998. The scheme of the study material and the growing practice and parameters measured each year are presented in Table 1. More detailed information can be found in original publications III–V and in the references cited therein.

The data concerning leaching of the fungicide triadimefon ((1-(4-chlorophenoxy)-3-3-dimethyl-1-(1H-1,2,4-triazol-1-yl)-2-butone), Bayleton 25®) and the insecticides cypermethrin (cyano(3-phenoxyphenol)methyl 3-(2,2-dichloroethynyl)-2,2dimethyl-cyclopropanecarboxylate), Ripcord ®) and alpha-cypermethrin ([1α(S*), 3α]-(±)-cyano(3-phenoxyphenol)methyl 3-(2,2-dichloroethynyl)-2,2dimethyl-cyclopropanecarboxylate, Fastac®) from peat medium in birch production are published in this thesis. These pesticides were analyzed from the leachate and soil water samples collected in experiments with fertilizer in soluble and slow-release form in production of container birch seedlings (IV), and the study material is described in article IV. In 1997 two applications of Bayleton 25 (July 29 and August 29) and one application of Ripcord (July 28) were made with a backpack sprayer (Solo 40123, Solo Kleinmotoren GmbH, Germany). In 1998 the application dates for Bayleton 25 were July 31 and August 14, and for Fastac July 15 and August 4.

In the leaching study presented in article III, about half of the applied nutrients was premixed into the peat medium, as is usual

**Table 1.** Scheme of the leaching studies and measurements. Fertilizer treatments for birch, PF= GP (1997) and ST (1998) fertilizer premixed into peat + fertigation, P-VN=fertilizer "Vital Nursery" premixed into peat, P-N= ST fertilizer + NutricoteT70 fertilizer premixed into peat, see Tables 1 and 2 in article IV.

| Year | Tree species | Container type | Fertilizer treatment | Analyses of leachate Nutrients | Analyses of leachate Pesticides | Analyses of soil water Nutrients | Analyses of soil water Pesticides | Measurem. of seedl. | Article |
|---|---|---|---|---|---|---|---|---|---|
| 1995 | Birch<br>Pine<br>Spruce | Plantek<br>Ecopot<br>Ecopot | Premixed fertilizer ST + fertigation | N tot.<br>$NO_3$-N<br>$NH_4$-N<br>$PO_4$-P | | | | Morphology<br>Nutrient contents | III |
| 1996 | Pine | Ecopot<br>Plantek | Premixed fertilizer ST + fertigation | Same as in 1995 | Chlorothalonil | | | Same as in 1995 | III, V |
| 1997 | Birch | Plantek | PF<br>P-VN | Same as in 1995 | Triadimefon*<br>Triadimenol<br>Cypermethrin | Same as from leachate | Same as from leachate | Morphology<br>Nutrient contents | IV<br>* publ. here |
| 1997 | Pine | Ecopot<br>Plantek | Premixed fertilizer ST + fertigation | | Chlorothalonil<br>Propiconazole | | Chlorothal. | | V |
| 1998 | Birch | Plantek | PF<br>P-VN<br>P-N | Same as in 1995 | Triadimefon*<br>Triadimenol<br>Alpha-cyperm. | Same as from leachate | Same as from leachate | Same as in 1997 | IV,<br>*publ. here |
| 1998 | Pine | Plantek | Premixed fertilizer ST + fertigation | | Chlorothalonil<br>Propiconazole | | Chlorothal. | | V |

in Finnish nursery practice; and the other half was fertigated (see Tables 3 and 4, III). According to the peat supplier, over 40% of the premixed N was in the form of ammonium, slightly less than 40% as methylene urea (= ureaformaldehyde) and the rest, about 15%, mainly as nitrate. In fertigations, about 50% of the N was applied as urea, 37% as nitrate and over 10% as ammonium. About 75% of the P in ST fertilizer premixed into peat was water-soluble ($(NH_4)_2HPO_4$) and all the P in Superex fertilizers used in fertigations was water-soluble ($KH_2PO_4$). Nutrient concentrations of Superex fertilizers and ST fertilizer are presented in Table 2 in article I.

In the birch experiment (IV) the PF treatment was the same as described above. In the P-VN treatment, four kilograms of the fertilizer "Vital nursery" ("Taimiston kestolannos", Kemira Corp., Finland) were premixed by the peat producer into one cubic meter of peat. The source of N in the fertilizer was methylene urea. Part of the P, K and Mg was also in slow-release form; the source of these forms was apatite for P and biotite for K and Mg. In the P-N treatment, two kilograms of coated slow-release fertilizer, Nutricote T70, in addition to the amount of fertilizer used in the PF treatment, were premixed by the peat producer into one cubic meter of peat (see Tables 1 and 2, IV).

**Figure 3.** Leachate collector with plate and vessel. One-year-old Norway spruce seedlings in Plantek 81F container tray (photographed by Pekka Voipio).

### *3.2.1 Collection of leachate and soil water*

The water percolated from container medium was collected with the same system in all experiments from May to October–November. Sloped polystyrene plates (40 x 40 cm or 40 x 60 cm) equipped with a hole and a sampling vessel were placed under container trays (Figure 3). The number of container trays varied from 3 to 6 according to tree species and year (Table 2, III, and n = 4 per treatment in IV and V). The trays were placed systematically among the commercial production stock. The volume, the electrical conductivity (EC) and pH of leachates were measured daily (excluding Saturday and Sunday) in 1995 and weekly in other years. When amounts of leachate were small and EC values were at the same level, samples from two to four successive sampling times were pooled before nutrient analyses. The samples were stored frozen for 4–6 months until analyzed for nutrients or pesticides.

Soil water was collected using tension lysimeters (ceramic cups) (Figure 2). The lysimeters were installed at a depth of 0.5 m beneath two greenhouses in 1996 and 1997. The birch greenhouse included 16 lysimeters collecting water from three different points and the pine greenhouse another 16 lysimeters collecting water from four different points.

### 3.2.2 Nutrient and pesticide analyses from water samples

The leachate samples were coloured, obviously caused by humic compounds; and in the water there was suspended material. Samples were not, however, filtered before the analyses. Total N in the water samples was measured by a method that uses oxidative digestion with peroxodisulfate. The sum of $NO_3$-N and $NO_2$-N was determined by the FIA (flow injection analysis) method, and $NH_4$-N and $PO_4$-P were analyzed spectrophotometrically. The fraction of organic N was determined by subtracting inorganic N from total N.

Pesticides were extracted from water samples with dichlorometan; the extraction was concentrated, and pesticides were analyzed by gas chromatography-mass spectrometry using the SIM-technique. In addition to triadimefon, also the degradation product, triadimenol, was measured from water samples. The limit of detection for the analyzed pesticides was as follows: 0.05 $\mu g l^{-1}$ for triadimefon and triadimenol, 0.1 $\mu g l^{-1}$ for chlorothalonil, 0.25 $\mu g l^{-1}$ for propiconazole and alpha-cypermethrin, and 1 $\mu g l^{-1}$ for cypermethrin.

### 3.2.3 Seedling measurements

During the growing season, the height growth of seedlings was measured weekly (III and IV). When leachate collection was stopped, the seedlings were harvested; and their height and root collar diameters were measured. Leaves, stems with branches (later referred to as stems) and roots were separated and dried (roots after washing) for 48 hours at 60°C before they were weighed. For nutrient analysis, the leaves, stems and roots were pooled separately by trays. The number of seedlings measured per tray varied according to tree species (Table 2, III), because the number of seedlings varied, depending on container type (Table 1, III).

### 3.2.4 Statistical analyses

The differences between treatments were analyzed either with a t-test (two treatments, IV, V) or with one-way ANOVA combined with Tukey's Multiple Range Test (three treatments, IV) using the SPSS Win7.0 program. In the analyses the sample trays for each treatment were used as replicates, although for practical reasons these trays were placed systemically among the commercial production and they were not true independent replicates.

# 4 Results

## 4.1 Use of fertilizers and nutrients

According to annual inventories, the nurseries surveyed used 175 000 kilograms of fertilizers in 1996 (I). Altogether the nurseries used 21 different fertilizer products to grow bareroot seedlings. The four most commonly used products, however, made up 74% of the total amount. About 66 000 kilograms were applied to the container stock, mostly in liquid form; and about 12 000 kilograms of fertilizers were premixed into peat growing medium.

On the basis of area, assuming that the total amount of N and P was applied to the whole production area, about 50 kilograms more N were applied to the production areas for container seedlings than to areas for bareroot seedlings (Table 2). The use of P was about two times higher in container than in bareroot areas. Per shipped seedling, however, the nurseries used about eight times more N and five times more P for growing a bareroot seedling than for a container seedling (Table 2). Container seedlings were shipped to the forest when one or two years old and bareroot seedlings mainly when four years old.

**Table 2.** Mean amounts of N, P and pesticides (per mg per grown and shipped seedling and kg per hectare) used (N and P both premixed and fertigated) by nurseries on the basis of annual inventories. In production of container seedlings the values could be compared with values calculated on the basis of lot-based information, the rows labelled " container, lot-based".

| | N | P | Herbicides | Fungicides | Insecticides | Pesticides |
|---|---|---|---|---|---|---|
| | | | mg per shipped seedling (pesticides as a.i.) | | | |
| Container | 102 | 51 | 0.9 | 1.6 | 0.9 | 3.4 |
| Bareroot | 822 | 237 | 7.9 | 5.6 | 1.2 | 14.7 |
| | | | mg per grown seedling (pesticides as a.i.) | | | |
| Container | 83 | 41 | 0.7 | 1.2 | 0.7 | 2.2 |
| Container, lot-based | 37–147 | 17–60 | 0–0.1 | 0.1–1.4 | 0.01–0.3 | 0.14–1.7 |
| | | | kg $ha^{-1}$ (pesticides as a.i.) | | | |
| Bareroot | 129 | 38 | 1.5 | 2.4 | 0.5 | 3.9 |
| Container | 180 | 86 | 0.4 | 1.8 | 1.0 | 2.4 |
| Container, lot-based | 160–234 | 69–102 | 0.1–2.5 | 0.9–8.4 | 0.2–2.5 | 0.9–9.5 |

## 4.2 Production practices in container nurseries

Over 70% of the conifer seedlings were grown in plastic-laminated paper containers, Ecopots (Lännen Inc., Finland) (I). The volume of the Ecopot cavities used for pines was usually 75 $cm^3$, and for spruce either 103 or 152 $cm^3$. The respective seedling densities were 898, 620, 430 seedlings per $m^2$. Only 5% of the conifer seedlings were grown in hard plastic containers, Plantek 81F (V=85 $cm^3$, 549 seedlings per $m^2$, Lännen Inc.). However, almost half of the birch seedlings were grown in hard plastic containers, Plantek 25 (V=380 $cm^3$, 156 seedlings per $m^2$, Lännen Inc.). All nurseries, with one exception, used commercial *Sphagnum* peat as growing medium. Fertilizer and magnesium-rich limestone had been premixed into the peat by the suppliers.

About 75% of the whole greenhouse area was irrigated by mobile booms, but in outdoor areas mainly basal irrigation sprinklers were used. Most nurseries grew the first season's spruce seedlings in greenhouses until October, and the second season's spruce seedlings were grown on outdoor growing areas. The time in the greenhouse varied most for pine (36–94 days) and birch (31–112 days).

Almost all nurseries measured the electrical conductivity (EC) of press-water extracts weekly to determine the need for fertigation. Sixty per cent of the nurseries considered EC to be the most important factor in determining the need for fertilization. About half of the nurseries followed seedling growth by measuring the height of seedlings either weekly or biweekly. Samples either from seedlings or from growing medium (from peat or press-water extracts) were seldom sent to laboratories for nutrient analyses.

The nurseries began to fertigate about one month after sowing; the range among nurseries was 11 to 77 days. On average, the nurseries applied fertilizers once a week, which meant about 8 to 12 applications during the growing season. Some nurseries fertigated only 2 to 4 times, but others fertigated almost 40 times during the growing period. Because of the different intervals between fertilizer applications, the rates applied at one session differed considerably, from 3 to 41 kg N $ha^{-1}$. However, within one nursery the rates of fertilizer application were about the same throughout the whole fertigation period. All nurseries used commercial fertilizer products, and 80% of the amounts used were Superex fertilizers (Kekkilä Corp.).

## 4.3 Percolation of water through container trays

Depending on tree species, 11 to 31% of the applied water (irrigation + precipitation) percolated from the trays (see Figure 2, III). During

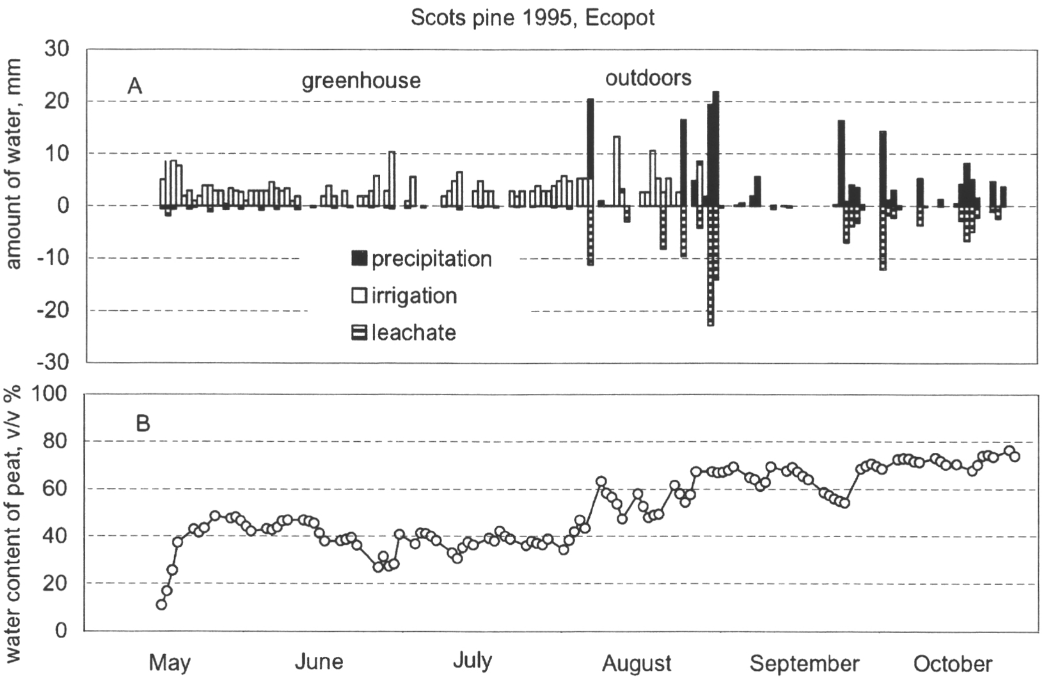


**Figure 4.** In Figure A are presented the amounts of water applied (irrigation + precipitation) and the amounts of leachate (mm) produced daily (excluding Saturday and Sunday) in production of container pine seedlings in 1995. In Figure B is presented the water content of peat medium as a proportion of the peat volume in container trays.

the greenhouse period, percolation was less than 10%. In the autumn, 50 to 70% of rainwater percolated through the trays, because during rainy periods with decreased evapotranspiration the water content of peat medium exceeded the container capacity (Figure 4). According to survey study, the length of period which seedlings were in the greenhouse varied a lot among nurseries and tree species (see Figure 2, I). In leaching studies, the growing periods in the greenhouse were about the average length of time used in nurseries (see Figure 1, III).

## 4.4 Nutrients in container production

### *4.4.1 Amounts of nutrients applied*

According to lot-based information, the amounts of N and P applied in fertigation varied greatly among nurseries (see Figure 3, I). The nursery with the greatest use of fertilizers applied about six times more N and P than the nursery with the smallest use of fertilizers. Often there were one or two nurseries that differed from the others.

**Table 3.** Mean amounts of nitrogen (N) and phosphorus (P) premixed and fertigated by Finnish nurseries and by Suonenjoki nursery in leaching studies and the amounts leached. For fertilizer treatments for birch, see legend in Table 1. n=number of nurseries.

| Tree species, Year, Fertilizer treatment | Finnish nurseries, Applied, kg ha$^{-1}$ N | P | Suonenjoki nursery, Applied, kg ha$^{-1}$ N | P | Suonenjoki nursery, Leached, kg ha$^{-1}$ N | P | Article |
|---|---|---|---|---|---|---|---|
| Birch | n=13 | | | | | | |
| 1995 | | | 260 | 108 | 41 | 56 | III |
| 1996 | 234 | 102 | | | | | I |
| 1997 PF | | | 172 | 70 | 36 | 37 | IV |
| 1998 PF | | | 157 | 78 | 9 | 35 | IV |
| 1997 P-VN | | | 268 | 119 | 24 | 20 | IV |
| 1998 P-VN | | | 334 | 130 | 46 | 20 | IV |
| 1998 P-N | | | 389 | 132 | 48 | 41 | IV |
| Pine | n=15 | | | | | | |
| 1995 | | | 183 | 72 | 23 | 46 | III |
| 1996 | 215 | 101 | | | | | I |
| 1996 | | | 164 | 67 | 19 | 11 | III |
| Spruce 2-y. 1. season | n=12 | | | | | | |
| 1995 | | | 190 | 78 | 26 | 20 | III |
| 1996 | 160 | 70 | | | | | I |
| Spruce 2-y. 2. season | n=13 | | | | | | |
| 1995 | | | 185 | 84 | 35 | 15 | III |
| 1996 | 175 | 69 | | | | | I |

Depending on tree species, when the amount of nutrients applied in premixed fertilizer were included, the nurseries applied 160–230 kg N ha$^{-1}$ and 70–100 kg P ha$^{-1}$ annually (Table 3). Slightly less N and P were applied annually to spruce seedlings grown for two years in the nursery than the birch and pine seedlings grown for one year in the nursery.

Although the coverage of the survey was good, the results are based on only one year, which does not give information about results in different types of weather. Obviously, fertilization varies between years. For example, the Suonenjoki nursery applied almost half as much N and P to birch seedlings in 1998 (treatment PF, IV) as in 1995 (Table 3).

The fertilizer type can also influence the amounts of nutrients applied. In a leaching study with slow-release fertilizers, the applied amounts of N and P, as recommended by the manufacturers, were about two times greater in the P-VN and P-N treatments than in the PF treatments (Table 3) (IV).

### *4.4.2 Amounts of nutrients leached*

The leaching of N differed among tree species, years and fertilizer treatments (Table 3) (III and IV). In birch seedling production, almost 50% of the total N recovered in the leachates occurred during May and early June (see Figure 3, III). About 50 to 90% of the N leached from conifer trays during July and August (= fertigation period). On the basis of the leaching study, in birch production the use of slow-release fertilizes instead of fertilization used in Finnish nurseries (treatment PF) does not necessarily diminish the leaching of N from containers into the ground (Table 3). The differences in amounts of leached N between treatments occurred during the first growing weeks, since the N leached mainly (60 to 80%) during May and June (see Figure 1, IV). In 1998 the nursery managed to irrigate the container trays of the PF treatment so that almost all water was retained in peat medium; because of a small amount of leachate, the amounts of leached N were small compared to that in the P-VN and P-N treatments (see Figure 1, IV). After June the amounts of leached N were the same in all treatments.

The amounts of P recovered in leachates varied greatly among tree species and years (Table 3). A partial explanation for this result may be that the P concentrations were measured from only one leachate replicate per tree species and container type in 1995 and 1996, and therefore the results include some uncertainty. In birch production, $PO_4$-P leached significantly less from the P-VN treatment than from PF and P-N treatments (see Figure 1, IV). Although the amounts of P leached per unit area were about the same as the amounts of N leached, a much greater proportion of applied P leached from container trays compared to the proportion of N leached (Figure 5).

### *4.4.3 Nutrient load*

In the production of container seedlings, the total nutrient load consists of the amounts of nutrients leached from containers into the ground and fertigated directly into the ground alongside and between the seedling containers. Depending on the containers and their layout within the nursery, the amounts of nutrients leached may be smaller than the amounts of nutrients fertigated directly onto the ground.

In pine and spruce production, the container trays usually cover the whole production area, i.e. the fertigation falls outside containers only around the blocks of container trays. In a greenhouse (50 m x 11 m = 550 $m^2$), the irrigation could overlap from 0.5 to 1.5 meters (the middle aisle and sides) the area covered by container trays, which means that from 10 to 20% of the nutrients are applied outside the

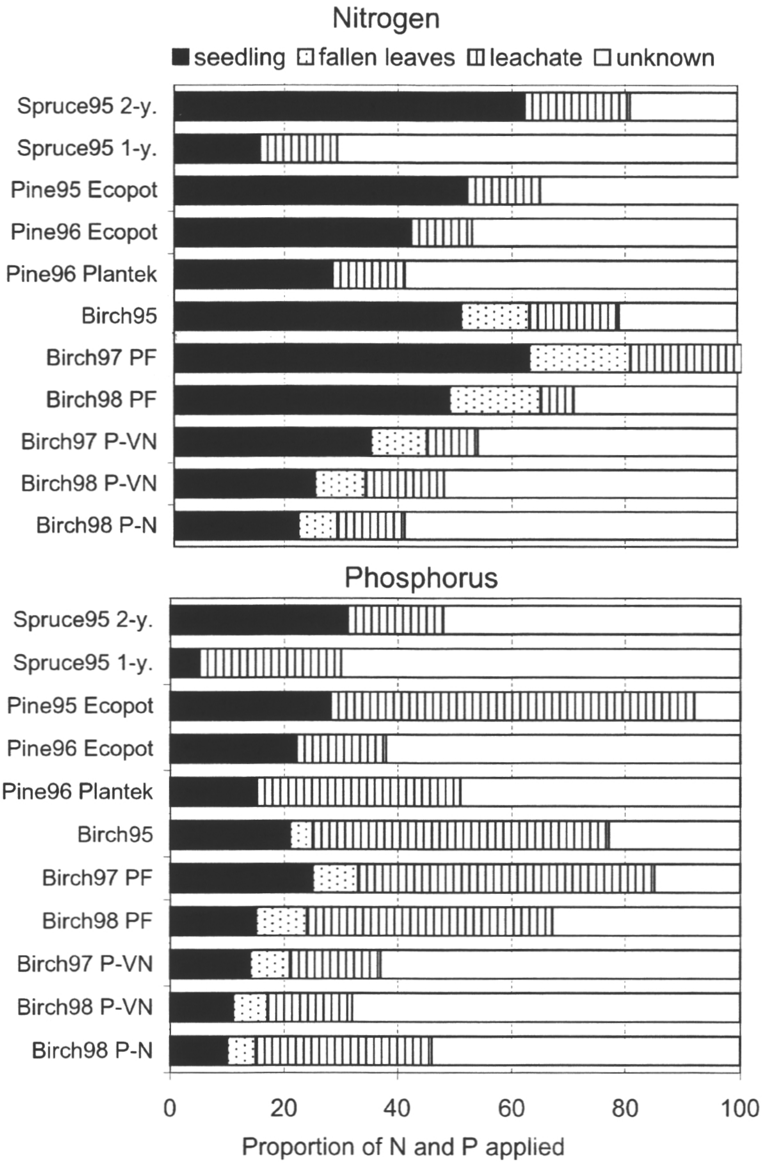


**Figure 5.** Proportion of applied N and P recovered in seedlings (shoots and roots), in fallen leaves (birch), in leachate, and the unknown proportion by tree species, by container type for pine, by fertilizer treatment for birch (PF = GP (1997) and ST (1998) fertilizer premixed into peat + fertigation (see Table 1, IV), P-VN = fertilizer "Vital Nursery" premixed into peat, P-N = ST fertilizer + Nutricote T70 fertilizer premixed into peat) and by year (ending 95 = 1995, ending 96 = 1996 etc.).

seedlings. Based on the results from pine production in 1995, it could be estimated that fertigation outside seedlings and leaching were of the same magnitude (17 and 18 kg N ha$^{-1}$, respectively) (III).

In birch production, the situation is different because most nurseries placed the birch container trays about 20 cm from each other before fertigations started. The separation caused the container trays to cover about half of the total irrigation area; i.e. about half of the irrigation (fertigation) water fell outside the containers. Based on the leaching study in 1995, the load caused by fertigations was much greater, 88 kg N ha$^{-1}$, than that caused by the amounts of N leached, 20 kg N ha$^{-1}$ (III).

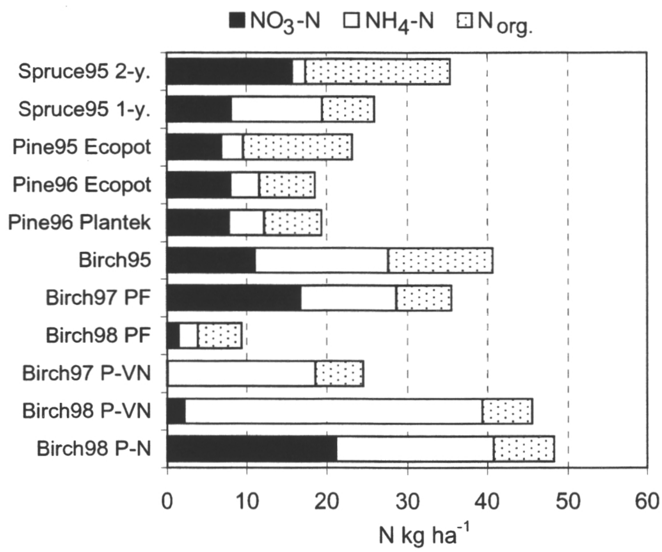


**Figure 6.** Leached amounts of $NO_3$-N, $NH_4$-N and organic N by tree species, by container type for pine, by fertilizer treatment for birch (see legend in Figure 5) and by year (ending 95 = 1995, ending 96 = 1996 etc.)

When slow-release fertilizers were premixed into peat growing medium, no fertigations were given in birch production, i.e. no nutrients were applied outside the container trays. The whole load was due to the amounts of N leached from container trays. In 1998 the N total load in the P-VN treatment was 23 kg N $ha^{-1}$ and the total N load in the PF treatment was 30 kg N $ha^{-1}$ (IV). If the amount of N premixed into peat in the PF treatment (108 kg $ha^{-1}$, Table 2, IV) had also been fertigated, the fertigation would have caused a N load of 54 kg N $ha^{-1}$.

### *4.4.4 N compounds leached*

N was found in leachates as nitrate, ammonium and organic N. Depending on tree species, 24 to 54% of the N leached as $NO_3$-N (III). Regardless of the tree species, however, the leached amounts per unit area were in the range 10 to 20 kg $NO_3$-N $ha^{-1}$ (Figure 6). In birch production, when all N premixed into peat was in the form of methylene urea (treatment P-VN, IV), only small amounts, 0.1 to 5 kg $ha^{-1}$, leached as $NO_3$-N.

N leached mainly as ammonium from birch and first-season spruce containers (III). In particular, when N was premixed into peat as methylene urea, about 80% of the total N in leachates was in the form of ammonium (IV). From the PF and P-N treatments similar proportions (30 to 40%) of N leached as $NO_3$-N and $NH_4$-N.

The proportion of organic N of the total amount of N leached was 14 to 59%. In all leachate samples almost all the leached N was in organic form after the end of August. In addition, small amounts of organic N were measured in leachates throughout the growing season.

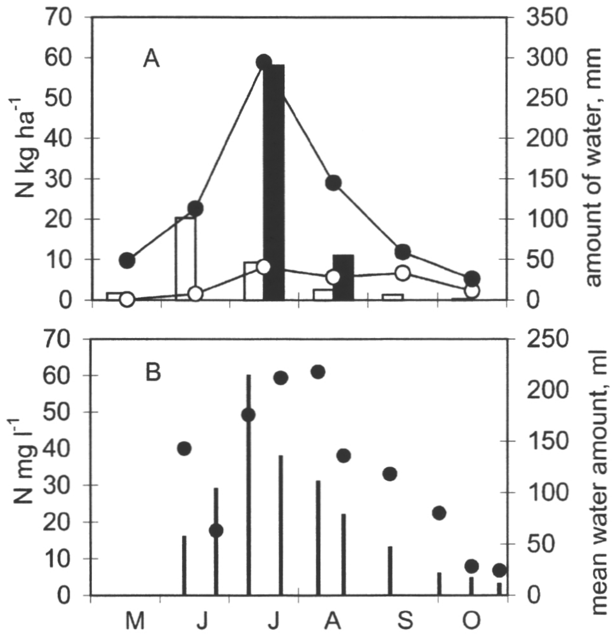


**Figure 7.** In Figure A is presented the monthly amount of water applied (black dots) and leached (white dots) and the monthly amount of N fertigated (black bars) and leached (white bars) in birch production. In Figure B is presented the mean amount of soil water (black dots) collected in ceramic cups (n = 8) during two- to three-week periods and N concentration of pooled samples of soil water (bars).

### *4.4.5 Soil water beneath pine and birch container areas*

After the birch container trays were placed 20 cm apart at the end of June, the different lay-out of pine and birch containers in greenhouses influenced the leaching of water and nutrients in the soil beneath the containers.

In pine production, the small amounts of leachate, from May to July less than 10 mm per month and from August to October less than 100 mm per month, and complete container tray cover caused a small hydrological load. In these conditions the downstream flow of water beneath containers was small, which could be seen in the amounts of water collected by lysimeters (V). In 1997 the lysimeters sucked up water poorly, six cups not at all. In 1998 some water samples were collected when the soil above the lysimeters was twice watered artificially.

Beneath the birch container area the situation was different. Separation of the containers increased the hydrological load. For example, in July the amount of water applied on the ground without container cover was 300 mm, while the amount leached was only 50 mm (Figure 7A). Most of the nutrients were fertigated in July 1997 (Figure 7A), which means that this load was concentrated to a short period of time. In contrast, the load caused by leached N was spread over the whole growing period but was greatest in June (Figure 7A). The increased N load and irrigation volume increased both the water volumes collected by ceramic cups and the N concentration in soil water (Figure 7B). The soil water contained nitrate and organic N compounds, but

**Table 4.** Mean amounts of nitrogen (N) and phosphorus (P) premixed and fertigated by Finnish nurseries and by Suonenjoki nursery and the amounts and proportions recovered in seedlings in leaching studies. For fertilizer treatments for birch, see legend in Table 1. n=number of nurseries.

| Tree species, Year, Fertilizer treatment | Finnish nurseries, Applied, mg per seedling | | Suonenjoki nursery, Applied, mg per seedling | | Suonenjoki nursery, Recovered, mg per seedling | | Proportion, recovered to applied, % | |
|---|---|---|---|---|---|---|---|---|
| | N | P | N | P | N | P | N | P |
| Birch | n=13 | | | | | | | |
| 1995 | | | 167 | 69 | 105 | 17 | 63 | 25 |
| 1996 | 147 | 60 | | | | | | |
| 1997 PF | | | 110 | 45 | 89 | 16 | 81 | 33 |
| 1998 PF | | | 101 | 50 | 66 | 13 | 65 | 24 |
| 1997 P-VN | | | 173 | 76 | 77 | 16 | 45 | 21 |
| 1998 P-VN | | | 214 | 83 | 73 | 15 | 34 | 17 |
| 1998 P-N | | | 249 | 85 | 72 | 13 | 29 | 15 |
| Pine | n=15 | | | | | | | |
| 1995 | | | 30 | 12 | 15 | 3.3 | 52 | 28 |
| 1996 | 37 | 19 | | | | | | |
| 1996 | | | 26 | 11 | 11 | 2.3 | 42 | 22 |
| Spruce 2-y. 1. season | n=12 | | | | | | | |
| 1995 | | | 44 | 18 | 7 | 0.9 | 15 | 5 |
| 1996 | 37 | 17 | | | | | | |
| Spruce 2-y. 2. season | n=13 | | | | | | | |
| 1995 | | | 43 | 19 | 27 | 6.1 | 62 | 31 |
| 1996 | 38 | 17 | | | | | | |

little ammonium ($NH_4$-N < 1 mg $l^{-1}$). In all soil water samples the concentrations of $PO_4$-P were less than 1 mg $l^{-1}$ (IV).

### *4.4.6 Efficiency of nutrient use by container seedlings*

The N and P content of seedlings varied from 15 to 63% of the applied N and from 5 to 33% of the applied P (Figure 5) (III, IV). If the nutrient content of fallen birch leaves was included, in 1997 the N content of seedlings increased to as high as 81% in the treatment where the seedlings were grown according to nursery practice (PF treatment) (Table 4). In the leaching study where seedlings were fertilized according to nursery practice (PF treatments for birch) the amounts of N and P applied to seedlings were similar to the mean amounts applied by the survey nurseries in 1996 (Table 4).

The nutrient contents were calculated from the standpoint of the seedlings so that the amounts nutrients applied outside the seedlings were not included into the amounts applied (III, IV). With this calculation method, the efficiency of N use by birch seedlings was lowest in those treatments in which part or all of the N was premixed into peat in slow-release form (IV). However, if the N fertigated outside seedling

**Table 5.** Use of pesticide types on different areas inside nurseries according to the survey study.

| Pesticide type | Applied amounts kg (as a.i) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Container seedlings | Bareroot seedlings | Outdoor areas | Fallow fields | Edges | Total | % of total |
| Herbicides | 35 | 87 | 58 | 39 | 37 | 277 | 42 |
| Fungicides | 160 | 87 | | | | 267 | 40 |
| Insecticides | 85 | 19 | | | | 118 | 18 |
| Total | 280 | 193 | 58 | 39 | 37 | 662 | |
| % of total | 42 | 29 | 9 | 6 | 6 | | |

trays was included, the efficiency difference was smaller. There the N efficiency varied from 50 to 62% for PF treatments (fertigation) and from 29 to 45% for P-VN and P-N treatments (IV).

## 4.5 Pesticides

### *4.5.1 Use of pesticides*

The nurseries surveyed used 662 kilograms of pesticides (as a.i.) in 1996 (II). Herbicides, fungicides and insecticides made up 42%, 40% and 18% of the total amount of pesticides, respectively (Table 5). Although the total number of products used was 39, in kilograms (as a.i.) the use of most products was very small. The six most commonly used products, two from each pesticide group, made up 76% of the whole amount.

About half of the amount of herbicides used was applied on sites without seedlings, e.g. adjacent, on non-production fields and edges, and a third on bareroot fields (Table 5). Only a few nurseries used chemical control in an attempt to prevent weeds from growing in containers. Over a third of the amount of herbicides applied on container seedlings was used to prevent the growth of liverworts. The most used herbicides were terbutylazine (Gardoprim-Neste®) and glyphosate (Roundup®).

The largest number of pesticide products was used in growing Scots pine seedlings. The number of pesticide applications was largest and the chemical control season was longest for growing pine (II). There was, however, great variation between nurseries in the use of chemical control. One nursery applied fungicides to pine seedlings only three times, while another nursery made 19 applications. Some nurseries used no chemical control in growing Norway spruce, while one nursery made five fungicide applications. The most used fungicide was chlorothalonil (Bravo 500®), which accounted for half of the total amount of fungicide used.

Of the 118 kilograms of insecticides used by nurseries in 1996, about 25 kilograms was used to prevent pest damage in nurseries.

About half of the nurseries, regardless of tree species, prevented insect damage with chemical control in June and July 1996. Almost 80% of the total amount of insecticides was used to prevent seedling damage caused by the pine weevil in the forest after planting. Seedlings were sprayed with permethrin products some days before they were shipped to the forest for planting, usually in spring.

### *4.5.2 Amounts of pesticides used per unit area*

Based on the total area of the nurseries and their use of pesticides, the nurseries applied, on average, 1.7 kg pesticides (a.i) $ha^{-1}$ annually (II). The range, including all nurseries, was from 0.1 to 4.8 kg $ha^{-1}$. The fields of bareroot seedlings were treated, on average, with 3.9 kg of pesticides (a.i.) per hectare, the range being 0.6 to 13.2 kg $ha^{-1}$. On areas without seedlings the amounts of pesticides applied varied from 0.5 to 2.4 kg $ha^{-1}$. These values are, however, imprecise because the questionnaire did not ask about exact areas of application. According to lot-based information, the tree species influenced the amounts of pesticides used in container seedling production (II). The mean amounts of pesticide use were largest for pine seedlings (9.5 kg $ha^{-1}$) and smallest for spruce seedlings (0.9 kg $ha^{-1}$) (see Figure 1, II).

### *4.5.3 Pesticides in leachates and soil water*

The seedling canopy and peat medium adsorbed pesticides effectively. During the growing period, less than 4% of the applied chlorothalonil, triadimefon, cypermethrin and alpha-cypermethrin leached from the container trays (Table 6). Propiconazole was an exception; almost 30% of the applied amounts leached from Plantek containers in 1997. The amounts leached per unit area were, however, many times smaller than the amounts applied per unit area (Table 6).

The total doses applied in the leaching studies were almost the same as the mean doses applied by nurseries in 1996 (II). During the 1996 growing period, the nurseries that used these pesticides applied, on average, 6.6 kg chlorothalonil, 0.4 kg propiconazole, 0.22 kg triadimefon and 0.06 kg cypermethrin per hectare. The application frequencies of these pesticides in the leaching studies were also quite similar to those used by the survey nurseries.

When pesticides passed through the seedling canopy and peat medium, the concentrations of pesticide were thoroughly diluted. The concentrations in application solutions were from 300 to 2500 mg $l^{-1}$, but the mean weekly concentrations in the leachates were usually less than 100 μg $l^{-1}$. Fluctuation was typical of fungicide concentrations

**Table 6.** Amounts of pesticides applied and leached (as a.i.) from peat medium in production of container pine and birch seedlings grown in either Ecopot or Plantek containers in the years 1996–1998. The mean weekly concentrations of pesticides in leachates are also presented (range in parenthesis). The range of pesticide concentrations in samples of soil water is presented; in parenthesis the first number tells how many samples there were in which the concentration of pesticide was over the limit of detection, the second number tells how many samples were analyzed.

| | Applied kg ha$^{-1}$ | Leached grams ha$^{-1}$ | Leached % | Mean conc. in leachates µg l$^{-1}$ | Conc. in soil water µg l$^{-1}$ |
|---|---|---|---|---|---|
| Pine | | | | | |
| Chlorothalonil | | | | | |
| 1996 A, Ecopot | 11.7 | 6.9 | 0.1 | 20 (1–302) | Not meas |
| 1996 B, Ecopot | 11.7 | 81.9 | 0.7 | 72 (1–366) | . |
| 1997 Ecopot | 7.2 | 5.3±2.8 | 0.1 | 98 (3–722) | < 0.1 |
| 1997 Plantek | 7.2 | 10.3±1.0 | 0.1 | 34 (6–88) | (n = 0 / 3) |
| 1998 G, Plantek | 26.0 | 24.4±1.2 | 0.1 | 13 (0.3–72) | 0.4–2.4 |
| 1998 N, Plantek | 4.1 | 12.3±3.0 | 0.3 | 39 (11–90) | ( n = 4 / 15) |
| Propiconazole | | | | | |
| 1997 Ecopot | 0.625 | 24.6±10.6 | 3.9 | 94 (44–268) | Not meas. |
| 1997 Plantek | 0.625 | 183.1±32.1 | 29.3 | 340 (123–1008) | Not meas. |
| 1998 Plantek | 0.750 | 117.8±8.2 | 15.7 | 92 (34–285) | Not meas. |
| Birch | | | | | |
| Triadimefon + triadimenol | | | | | |
| 1997, Plantek | 0.118 | 0.9±0.3 | 0.8 | 0.9 (0.3–2.8) | < 0.25 (n = 0 / 6) |
| 1998, Plantek | 0.118 | 1.9±0. 9 | 1.6 | 2.0 (0.1–8.4) | 0.1–2.7 ( n = 2 / 26 ) |
| Cypermethrin | | | | | |
| 1997, Plantek | 0.024 | | | < 1.0 | < 1.0 (n = 0 / 6) |
| Alpha-cypermethrin | | | | | |
| 1998, Plantek | 0.048 | 1.8±0.5 | 3.7 | 1.4 (0.1–6.2) | 0.2–0.3 (n = 2 / 26 ) |

in leachates; the concentrations were usually highest after application and decreased before a new application (see Figure 2 and 3 in V). Repeated applications did not increase the concentrations of pesticides in the leachates.

In 1997 in production of pine seedlings, only three pooled samples of soil water were analyzed, but in 1998 the number of samples was 15 (Table 3, V). In 1998 the chlorothalonil concentration of four samples exceeded the limit of detection, 0.1 µg l$^{-1}$. The highest measured value was 2.4 µg l$^{-1}$. The samples that included chlorothalonil were collected from three different collecting points.

In 1997 tridimefon, triadimenol and cypermethrin were analyzed from six samples of soil water and in 1998 from 26 samples of soil water collected in the ceramic cups beneath the birch container area. During the 1997 growing period the concentration of pesticides analyzed did not exceed the limit of detection in any samples, but in 1998 triadimefon was found in one sample, triadimenol in another sample and cypermethrin in two samples (Table 6).

# 5 Discussion

## 5.1 Use of fertilizer and pesticides

Per shipped bareroot seedling, nurseries used about eight times more N, five times more P and four times more pesticides than per shipped container seedling. Most of the container seedlings were delivered for planting as one-year-old seedlings, while most of the bareroot seedlings were four years old. In Sweden, nurseries have applied even more nutrients to bareroot seedlings than in Finland (Nyström et al. 2001). According to this study and to the study of Nyström et al. (2001), both Finnish and Swedish nurseries had applied, on average, about 100 mg N per shipped container seedling. On the other hand, the use of P has been higher in Finnish nurseries than in Swedish nurseries, 51 and 15 mg P, respectively, per shipped container seedling.

The survey nurseries used 175 000 kilograms of fertilizer in 1996. More than half of that amount was used to grow 15 million shipped bareroot seedlings and the rest to grow 100 million shipped container seedlings. About half of the total amount of pesticides, 662 kilograms (a.i.), was used in bareroot seedling production and the other half in container seedling production. In Sweden the southern nurseries produced more bareroot seedlings and also used more pesticides than the northern nurseries, which produced mainly one-year-old container seedlings (Hannerz and Nyström 2002).

During the last twenty years the annual use of fertilizers in Finnish forest nurseries has decreased from about 800 000 to 200 000 kilograms, and the use of pesticides from about 18 000 to 1000 kilograms a.i (Rikala and Westman 1979, Kangas et al. 1980). The main reason for the decrease has been the increased proportion of container production. Another factor has been the decrease in total seedling production from 250 to 150 million seedlings. Most important reason for the decrease in pesticide use has obviously been the decrease in pine seedling production from 190 to 60 million seedlings, because, according to the survey, the largest amounts of pesticides were used in pine production. Another factor that may have had an influence is the change in pesticide products registered for nursery use. To obtain the desired effect with the new active ingredients, the doses required are usually lower than with the old ingredients.

When the total use of nutrients and pesticides decreases, this also means that an individual nursery uses much less nutrients and pesticides to grow the same number of seedlings at the beginning of the 2000s than at the beginning of the 1980s. Although the smaller use of fertilizers and pesticides already decreases the possible risk of contaminating the environment, environmental management of container seedling production could further mitigate the risk for contamination of surface and ground water.

## 5.2 Annual inventories *vs*. lot-based information

On the questionnaire the use of fertilizers and pesticides was asked in two ways: total use during the 1996 growing season based on annual inventories and use in growing certain seedling lots. These two approaches gave different results (Table 2). Apparently, according to the values obtained from lot-based information, it is not possible to calculate the total use. The amount of fertilizer that nurseries applied to empty spaces around container blocks explains part of the difference between these two values. Moreover, the timing of permethrin applications explains some of the difference in the use of pesticides. Two nurseries reported that they sprayed the monitored seedling lot in autumn, and only this use of pesticides was included in the calculations based on detailed information. One explanation could be that nurseries had used more fertilizer and chemical control in growing of seedling lots other than the monitored one. Another explanation could be that the amounts of pesticides that nurseries sprayed near the containers (paths and edges) and areas without seedlings were not included in the detailed information.

## 5.3 Growing practices in container production

The main materials required for seedling production, such as containers, peat and irrigation equipment, varied only slightly among Finnish nurseries. Most conifer seedlings were grown in Ecopots, but after the survey the use of hard plastic containers in conifer seedling production had also increased (Rikala 2000). Different types of hard plastic containers are also used in Sweden (Hannerz and Rosenberg 2001, Aldentun 2002). Peat is also the most frequently used growing medium in Sweden (Hannerz and Rosenberg 2001), while in North America peat is used as the base of growing medium; but other components such as vermiculite, perlite and sawdust are mixed into the peat (Dumroese and Wenny 1997, Rey 1997).

The practice of premixing soluble nutrients into peat seems to be common only in Finland. Obviously, some nurseries premix fertilizers, mostly in slow-release form, into growing medium in North

America (Landis et al. 1989a, Rey 1997), even though in the 1980s the most popular method was direct injection of liquid fertilizers into the irrigation system (=fertigation) (Landis et al. 1989a). In Finland about half of the N in the premixed fertilizer was in slow-release form, as methylene urea.

In 1996 the Finnish survey nurseries had more greenhouse area (26 ha) than the Swedish survey nurseries (18 ha) did (Nyström et al. 2001). The Swedish nurseries, however, produced about 210 million seedlings, while the Finnish nurseries produced 100 million. The Swedish nurseries apparently grow at least two crops per year in the same greenhouse (Aldentun 2002), while most of the Finnish nurseries kept the first season's spruce seedlings and also some pine seedling lots in greenhouses until autumn. On outdoor growing areas, the leaching of nutrients depends mainly on weather conditions, especially on the amount of precipitation (van der Boon and Niers 1983, III).

## 5.4 Fertilization practices and leaching of N and P

Premixing of fertilizer into peat growing medium can increase the risk of leaching nutrients. When the nutrient content of peat is large at the beginning of seedling growth, irrigation can cause nutrient leaching. In leaching studies, N, in particular, leached from birch containers in late May and early June, although about half of the N premixed into the peat was in slow-release form as methylene urea (III). The greater volume of birch container cells compared to the volume of conifer cells might have increased the leaching of nutrients in birch production. Premixing of all the N into peat medium in slow-release form did not affect the leaching of N at the beginning of the season (IV). Similar results have been obtained in other studies where the same or different types of slow-release fertilizer have been used (Rathier and Frink 1989, Cox 1993).

The abundant use of water-soluble P in ST fertilizer premixed into peat and in fertilizers used in fertigation, and the poor P adsorption capacity of the peat growing medium used in leaching studies and also in most Finnish nurseries, obviously, explain the large amounts of P leached. Nieminen and Jarva (1996) have shown that P adsorption was strongly correlated with the concentrations of iron in the peat samples collected from the 20 Finnish drained mires. Therefore, the P adsorption capacity of peat could have been low due to possible low concentrations of iron in peat. In birch seedling production (IV), the use of apatite as the main source of P in the P-VN treatment decreased the leaching of $PO_4$-P.

When a nursery uses a commercial peat product with premixed fertilizers, there is a delay between premixing of the fertilizer and the use of peat as a growing medium. In the leaching study with slow-release fertilizers (IV), the premixing was done about a month before germinants were transplanted, but in practice it could be over two months. The nurseries sowed from early April to mid-June, but obviously all the peat that the nurseries used for annual production was delivered to the nurseries all at once in March. If the delay between premixing and use is long, part of the nutrients in slow release form could be transformed to soluble form either in the peat bales or in containers filled with peat. If it is a question of coated fertilizer prills, the broken prills might also be one reason for increased concentrations in leachates (Huett and Morris 1999). If nurseries use growing medium premixed with fertilizers, they have to be conscious of the leaching risk when they begin growing seedlings.

Most Finnish nurseries fertigated periodically. According to Landis et al. (1989a), periodic fertilization means application of concentrated fertilizer solutions according to some fixed schedule, such as once a week. In the early 1980s, about 60% of the nurseries in North America used periodic fertilization and about 25% used constant fertilization (Landis et al. 1989a). In constant fertilization a dilute fertilizer solution is applied almost every time the crop is irrigated. Periodic fertilization obviously increases the risk of nutrient leaching. In the leaching study (III), the number of fertigations, 3–8 sessions during the growing season, was very low. These few fertigations must have caused high peaks in the nutrient content of the peat medium. When the nutrient content of peat is large, irrigation water and rain could leach nutrients. In 1995, for example, a heavy rainfall (10 mm) that occurred soon after one fertigation leached about one-third of the total N leached from the pine and second-season spruce container trays during the whole collection period.

The irrigation (fertigation) method used in Finnish forest nurseries was originally based on the studies of Puustjärvi (1977) and was discussed by Heiskanen (1993) and confirmed by Lähde and Savonen (1983) and by Heiskanen (1995). According to their conclusions, water availability and aeration are at optimum for the growth of tree seedlings when the water content of the light *Sphagnum* peat medium in containers is 40–50% of the peat medium volume (matric potential range –5 to –10 kPa). Lamhamedi et al. (2001) also concluded that a water volume of 30–45% of the volume of peat-vermiculate (3:1 v/v) substrate in large containers (350 $cm^3$) is optimum for growth of white spruce seedlings. According to the survey study (I), about half of the nurseries weighed the container trays weekly to check if the water content of the container trays was within the optimum level, although meanwhile the survey nurseries irrigated according to their experience and the weather conditions.

This weighing practice was also used in leaching studies, which obviously explains the small amounts of leachate and partly accounts for the small amounts of N and P leached compared to the amounts measured in horticultural studies, e.g. 300–600 kg N ha$^{-1}$ (van der Boon and Niers 1983, Broschat 1995). Depending on tree species, a total of 25 to 175 mm water leached from the containers (III), while in the study of Dumroese et al. (1995) the amounts of discharged water were as large as 450 to 800 mm. The use of different irrigation (fertigation) methods could explain this difference. Dumroese et al. (1995) irrigated according to the recommendation of Landis et al. (1989a): "The key consideration in applying liquid fertilizers is to apply enough solution each time to completely saturate the growing medium profile and flush out excess fertilizer salts". This method, in which nutrients are leached from containers, is widely used in the horticultural branch (Biernbaum 1992), and obviously also in North American forest nurseries. The greater the leachate fraction is, the higher is the risk of nutrient contamination of the environment (McAvoy et al. 1992).

## 5.5 Amounts of N and P leached and forms of N leached

The annual leaching of N in the production of container forest tree seedlings was not greater than the mean losses of N, about 18 to 20 kg ha$^{-1}$, from Finnish agricultural fields (Rekolainen et al. 1993). The P leached in substantially greater amounts than what had been measured from agricultural fields, 0.95 to 1.7 kg ha$^{-1}$ (Rekolainen et al. 1997). Although the results for amounts of N and P leached are from only one nursery, it was fairly representative of most forest nurseries in Finland. The number of fertigation times in the leaching study (III) was lower than the average (once a week) for all nurseries. The fewer fertigation times increased rather than decreased the amounts of N and P leached.

In horticultural production much higher values for nutrient leaching have been measured. Andersen and Hansen (2000) have, however, shown that by using drip irrigation and controlling fertigation with tensiometers, it is possible to minimize the leaching of N also in outdoor conditions. In their experiments, when the amounts of N applied were 80 to 287 kg ha$^{-1}$, the amounts of $NO_3$-N leached were 1 to 6 kg ha$^{-1}$. The use of drip irrigation in forest seedling production could be difficult because of the small volumes of the containers used.

The N leached in nitrate, ammonium and organic N form from the peat growing medium. The N forms, ammonium, urea and methylene urea, premixed into the peat and applied with fertigations explain the amounts of $NH_4$-N in the leachates. Another explanation could be the low pHs of the leachates. For example, throughout the whole growing period in P-VN treatments (IV), where the N was premixed into the peat as methylene urea, the pH in leachates was about 4. The acidic conditions in the growing medium may have slowed nitrification, and therefore no leachable nitrate was available in the medium. Hershey and Paul (1982) also found that in controlled-release fertilizer treatment about half of the N leached as nitrate and the other half as ammonium.

Part of the organic N presumably consisted of urea and methylene urea. Most of the organic N in leachates was found after September, and the amounts depended more on the amount of water percolated than on either tree species or fertilizer treatment. Explanations for the organic N in autumn could be the N contained in root exudates and/or N compounds originating from peat and/or microbes. Large concentrations of organic N have also been found in agricultural soils (Myrphy et al. 2000).

In many studies only the leaching of $NO_3$-N has been measured (Rathier and Frink 1989, Fare et al. 1994, Broschat 1995, Andersen and Hansen 2000), partly because $NO_3$-N levels of 10 mg $l^{-1}$ (USEPA 2001) or $NO_3$-levels of 50 mg $l^{-1}$ (=11.3 mg $NO_3$-N $l^{-1}$)(European Community 1998) in drinking water are considered unsafe for humans. If only $NO_3$-N concentrations in leachates had been measured, the total N leaching would have been estimated to be much smaller than what it was in reality (Figure 6). Therefore in forest nursery studies $NO_3$-N analyses apparently are not enough. At least total N analyses are needed.

## 5.6 Efficiency of fertilization and amounts of N and P applied

The efficiency of N use by birch seedlings was slightly better than that of conifer seedlings (III). When spruce seedlings were grown for two years in the nursery, the efficiency of N use by first-season seedlings was much lower than that of second-season seedlings. The results for Swedish nurseries are similar (Hannerz and Rosenberg 2001). The amount of N applied to the Swedish seedling lot was twice that applied to the Finnish lot. The efficiencies of N use by first- and second-season seedlings were, however, quite similar, 23% and 71%, respectively, for the Swedish lot and 15% and 62%, respectively, for the Finnish lot. Consequently, due to the greater N concentration and higher dry mass content of the Swedish seedlings compared to the Finnish seedlings, the N content of the Swedish seedlings was about twice that of the Finnish seedlings. However, these results have to be seen as preliminary, because they concern only one seedling lot in both countries.

Timmer and Armstrong (1987) showed that it is possible to grow similar seedlings with smaller amounts of fertilizer by changing the method of fertilization. When they applied nutrients daily as exponentially increasing additions instead of delivering the nutrition solution twice weekly at a constant rate of addition, the N content of seedlings was almost the same, even though the amount of N applied was only one-quarter of the conventional N dose. The efficiency of N use by seedlings fertilized at a constant rate was 16%, compared to 57% of the seedlings fertilized within exponentially increasing additions.

In addition to fertilization method, the growing conditions, e.g. weather (year) and container type, seemed to influence the N content of seedlings (III, IV). Folk et al. (1992) have shown that the peat used as growing medium can also influence the nutrient uptake of seedlings. In their experiment, the maximum difference in the N content of jack pine seedlings grown in different peat substrates was three-fold, despite similar additions of fertilizer. Timmer and Folk (1992) speculated that possible interactions between fertilizers and peat types could be reason for the different N content of jack pine seedlings.

The efficiency of N use by birch seedlings fertilized with slow-release fertilizer was lower (29 to 45%) than that (66 to 81%) of seedlings fertilized partly with liquid fertilizer (IV). One disadvantage of slow-release fertilizers is that the amounts of fertilizer applied have to be large enough to guarantee the desired growth of birch seedlings in Finnish growing conditions. When the amounts of N fertigated outside the seedlings were included in the efficiency calculations, the differences between fertilization systems were no longer so clear. The efficiency of N use by fertigated seedlings dropped to 50% (1998) and to 62% (1997).

The efficiency of P use by seedlings was low independently of tree species, year and fertilizer treatment (Figure 5). One reason for this could be the large amounts of P applied, which exceeded the need of seedlings. In fertilizers used by Finnish forest nurseries the P/N-ratio is high, 0.23–0.39, compared to the recommendation of Ingestad (1979), 0.14–0.16. In the fertilizers used most by Swedish nurseries the P/N-ratio, 0.12–0.20, is close to the recommendation of Ingestad, which explains the smaller use of P per shipped seedling in Swedish nurseries compared to that in Finnish nurseries (Nyström et al. 2001). Evidently, Finnish nurseries could also decrease the use of P.

Determination of the nutrient content of seedlings could be one means of developing the efficiency of fertilization. Those nurseries that already analyze the nutrient concentration of seedlings need to weigh the dry mass of seedlings (see Landis 1997). If a nursery could grow similar seedlings with smaller amounts of nutrients by changing either the fertilization system or the method, the increased efficiency of nutrient use could decrease the risk of contaminating the environment. High efficiency is not a value as such, but better use of resources has to be related to seedling quality (Mattsson 1997, Puttonen 1997), factors such as morphology and nutrient concentration and content of seedlings.

However, only the potential risk of nutrient leaching can be estimated by the nutrient content of the seedlings or the crop. According to leaching studies (III, IV), only part of the amount of N and P that the seedlings did not take up from applied N and P leached from container medium. Because the nutrients in the growing medium were not analyzed, it is not possible to know whether they remained in the peat medium in late October or whether N had volatilized into the atmosphere during the summer and autumn.

## 5.7 Chemical control of pests

The Finnish survey nurseries used 3.4 kg pesticides (a.i.) per million shipped container seedlings and 14.7 kg per million shipped bareroot seedlings (Table 2). The variation in pesticide use between individual nurseries was great (see Figure 1, II), as has also been found in Swedish studies (Persson 1992, Hannerz and Nyström 2002). In Sweden in the 1990s, depending on the study year and the location of nurseries the mean use of pesticides (excluding the use of permethrin products against pine weevil) varied from 1.5 to 16.9 kg pesticides (a.i) per million shipped seedlings (Hannerz and Nyström 2002). In 1992 the bareroot nurseries in the southern United States applied, on average, 9.0 kg pesticides (excluding fumigants) per million shipped bareroot seedlings (South and Zwolinski 1996). The magnitude of pesticide use has been the same in all these studies, and the use per shipped seedling has been smaller in container seedling production than in bareroot seedling production.

The Finnish survey nurseries used 39 different pesticide products in 1996, while in 2000 the southern Swedish nurseries used 26 and the northern Swedish nurseries used 13 different products (Hannerz and Nyström 2002). Although in both countries the number of products was quite large, in kilograms (as a.i.) the use of most products was very small, and the amounts of the two most-used products among the fungicides, herbicides and insecticides covered 50 to 90% of the total use. Because the pest situation in Finnish and Swedish nurseries has been different (see section 1.3.2), the nurseries used different products; during the years studied, only the fungicide propiconazole, the herbicides glyphosate, quinoclamine and terbutylazine, and the insecticide permethrin were common to both Finnish and Swedish nurseries.

In Finland the number of herbicide products was large. It was known that terbutylazine (Gardoprim-Neste®) would soon disappear from the market and the nurseries tried, by using other herbicides, to find new solutions for chemical control of weeds. In Finland about half of the herbicides were used on areas without seedlings. Weed control on all adjacent areas is important because these areas serve as a source of weeds both in outdoor areas and in containers (Juntunen 2000). However, outdoor areas and edges are places where the risk of herbicide leaching may be high, e.g. because of the low organic-matter content of the soil. Although the nurseries already used cloth to cover the empty spaces between containers, solutions other than chemical control for preventing the growth of weeds on sites without seedlings would be most welcome.

The annual rate of fungicide application to container pine seedlings (mean rate 8 kg $ha^{-1}$) was high compared to rates used in production of other tree species and agricultural crops. In addition, sprayings were carried out from early spring to late autumn, which meant that there was a risk of contamination during the whole growing period. When container seedlings are sprayed with pesticides, however, most of the pesticide is sprayed on the very densely growing seedlings; and the amount that leaches from the container trays causes the actual load, together with the amounts sprayed outside seedlings.

According to the leaching studies (V and data published in this thesis), the seedling canopy and the peat medium in containers effectively adsorbed the pesticides studied (Table 6); both the active ingredient and the container type, however, influenced the amounts of active ingredient leached from container trays. In pine production almost 30% of the applied propiconazole, but less than 1% of the applied chlorothalonil leached from the peat medium.

The different water solubilities of propiconazole and chlorothalonil, 100 and 0.9 mg $l^{-1}$ (Tomlin 1997), respectively, could be one reason for the differences in amounts leached. Bruhn and Fry (1982) have shown that rainfall removed cholorothalonil from the leaves of potatoes; the sooner after application the rainfall occurred, the greater was the removal. Because of the higher water solubility of propiconazole, removal of propiconazole from needles could have been even greater than that of chlorothalonil. Tuomainen et al. (1999) found no propiconazole on pine needles the eighth day after application; but after two weeks in nursery conditions about 30–50% of the chlorothalonil deposit measured after application remained on the needles.

Although there was not always rainfall and percolation of water after pesticide applications, a trend could be seen: fungicide concentrations in leachates were usually highest after pesticide application and decreased before a new application. Volatilization and photodegradation could also have influenced this result. Da Silva et al. (2001) have shown that, due to volatilization losses at temperatures over 25°C, the residues of tridimefon on the surfaces of plants and soils could decrease by about 60% in a few hours.

In addition to processes on needles and shoots, the processes in peat medium are obvious reasons for the small amounts of pesticides leached. Because triadimenol, the degradation product of triadimefon, was the only degradation product measured, it is not possible to know whether the reason for the small amount of leaching was adsorption of pesticides to peat and/or degradation of pesticides to their metabolites. More studies with different pesticides used on the different growing media are needed before it will be possible to say with certainty that the container production of forest seedlings has decreased the risk of environmental contamination by pesticides.

## 5.8 Water management

Water management is an important means of controlling contamination of the environment, because water carries both nutrients and pesticides. Water management includes two aspects: reduction of the amounts of water discharged in seedling production and management of waste water.

In the Finnish system of container seedling production the critical factor for amounts of leachate was the amount of time seedlings were outdoors. During the greenhouse period, the water content of the peat medium could be maintained within the optimum level (Figure 4), but outdoors the water content of peat medium increased due to the rain showers and rainy periods. In particular, in August and later in autumn, when evapotranspiration decreased, the water content of peat medium increased permanently to a high level. Consequently, 50 to 70% of applied water percolated from the trays (Figure 4). Lamhamedi et al. (2001) have also shown that the amounts of leachate increased exponentially as the water content of the peat-vermiculate (3:1 v/v) substrate increased from 20 to 60% of the total container volume.

In August the percolation of water also leached N and P from container trays, but after the beginning of September a maximum of 10% of the total N and 20% of the total P leached was found in leachates. The ending of fertigations at the beginning of August had obviously decreased the concentrations of soluble nutrients in growing medium so much that no leachable nutrients were left in the growing medium. However, the situation may be different, if fertigations continue longer than what the practice was in leaching studies. In conclusion, if the discharge due to rain were eliminated, the nutrient and pesticide load to the environment would decrease considerably. In Fennoscandian circumstances the covering of outdoor areas with movable roofs could be a solution worth studying.

Covering of outdoor areas could lead to positive effects in addition to decreasing the risk of contamination. If rain were excluded, it would be possible to maintain the water content of peat growing medium at optimum level and avoid lack of oxygen in the root zone during the rainy autumn months. Pesticides could be applied without the risk of leaching active ingredients from the leaves and shoots due to rain. Thus the effectiveness of chemical control could increase and the number of applications decrease.

Waste water can be managed in several ways (Dumroese et al. 1991), and the best solution depends on conditions in the nursery. The first step is to plan collection of the discharge water, and the second is treatment of the collected water. Recycling of waste water can be a solution, especially in situations where water supplies are limited or costly. Another solution could be treatment of waste water prior to its release into the environment. Constructed wetlands can be a good alternative for treatment of waste water (Berghage et al. 1999).

It is not possible to say when the amounts of water, nutrients and pesticides discharged are so high that waste water management is needed. Many factors related to nursery location influence the need to collect and treat discharged water; some of these are the depth of the water table, characteristics of the soil layers between the ground and the ground water reservoirs as well as proximity to rivers and lakes.

# 6 Conclusions

The amounts of nutrients and pesticides applied to container seedlings varied considerably among nurseries, even for growing the same type of seedling stock. The reasons for differences in fertilization and in chemical control cannot, however, be analyzed in a survey study. The published data, on the other hand, give individual nurseries the possibility to compare their practices and the amounts of chemicals applied with the amounts used in other nurseries and could thus provide the impulse for evaluation and development of growing practices.

Regardless of the small production area used for producing container tree seedlings compared to the area used for agriculture, forest nurseries may also be a risk for contamination of ground water, especially if the area used for seedling production is located on a ground water reservoir. In addition, two aspects connected with production of tree seedlings in containers can increase the risk: the same type of production continuing at the same place for years and most of the annual nutrient leaching occurring during one or two months. If a nursery is located near watercourses, the P and pesticides, which are toxic to aquatic animals, in runoff water could also be a risk.

Monitoring of seedling nutrition is needed in forest nurseries. According to the leaching study, however, losses of nutrients into the nursery environment due to leaching cannot be monitored with precision by using the nutrient content of seedlings, because only part of the nutrients not found in seedlings leached from the containers into the ground.

It is important to determine the amount of nutrients that fall outside seedlings during fertigations of container seedlings. If the fertigation area without seedlings is large compared to the area covered by seedling containers, it is important to try to minimize this area. Some solutions could be to use of mobile boom sprayers instead of sprinklers and to improve the lay-out of irrigation systems and/or that of the container trays.

The use of slow-release fertilizers could be one solution, but this includes uncertainties. Obviously, to obtain the desired growth of seedlings in Finnish growing conditions, large amounts of fertilizers have to be used. The risk for leaching of nutrients is high at the beginning of the growing period when the nutrient content of the growing medium is high and the uptake by seedlings is low. To minimize the risk of leaching, fertilizers have to be premixed into growing medium just before seedlings begin to grow, which could be difficult in practice, if commercial peat products are used. The influences of slow-release fertilizers on growth, on development of frost hardiness in autumn and on outplanting performance of seedlings are not well known. Indeed, the slow-release fertilizers include a large group of products with different properties, which means that the results concerning one product might not be valid for other products.

The change from bareroot production to container seedling production decreases the risk of environmental contamination by pesticides. One reason is the decrease in the amount of pesticides used per shipped seedling due to shorter growing times and higher seedling densities in production of container seedlings. The other reason is that smaller amounts of pesticides are applied directly onto the ground in container production than in bareroot production, which decreases runoff of pesticide into surface and ground waters. Third, the seedling canopies and the peat medium in containers effectively adsorb pesticides; the container type and the active ingredient, however, both influence the amounts of active ingredient leached from container trays.

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# I

New Forests **21:** 141–158, 2001.


# Fertilization practice in Finnish forest nurseries from the standpoint of environmental impact

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Accepted 9 April 2001

**Key words:** nitrogen, nutrients, phosphorus, seedling, survey study

**Abstract.** In 1996 a questionnaire concerning actual systems and practices used in production of seedlings was sent to 33 Finnish forest nurseries. A total of 28 nurseries answered the questionnaire. These replies represented about 80% of the total production of forest seedlings in Finland. The nurseries used about 200 metric tons of fertilizers in 1996, which was about 25% of the fertilizer use in 1976. Explanations for the decrease in fertilization are the shift from bareroot production to container production and the decrease in total production from 190 to 150 million seedlings. Finnish nurseries applied about 100 mg N and 50 mg P per container seedling shipped, and 820 mg N and 240 mg P per bareroot seedling. The mean annual applications of N and P in 1996 were about 180 kg/ha and 90 kg/ha for container stock and 130 kg N/ha and 40 kg P/ha for bareroot stock. However, the variation between nurseries was large.

## Introduction

Use of fertilizers can have an impact on the environment. For example, the leaching of nitrogen (N) compounds, especially nitrate, can contaminate groundwater (Brown 1991). Although the total use of fertilizers in nursery production is small compared to that in agriculture and horticulture, there can be risks because some nurseries are situated on areas where groundwater reservoirs form and where leachates may contaminate the groundwater. If, however, the use of fertilizers and the fertilization practices of nurseries are known, the potential risk for leaching of harmful nutrients can be analyzed. The prevailing culturing practice may greatly affect the environmental impacts of nurseries (Landis 1991; Alexander 1993).

The production of forest seedlings in Finland has changed greatly due to improved nursery technology and new growing practices. In the mid-1950s, when annual seedling production was about 23 million bareroot seedlings, growing practices differed greatly between nurseries and there was a need to

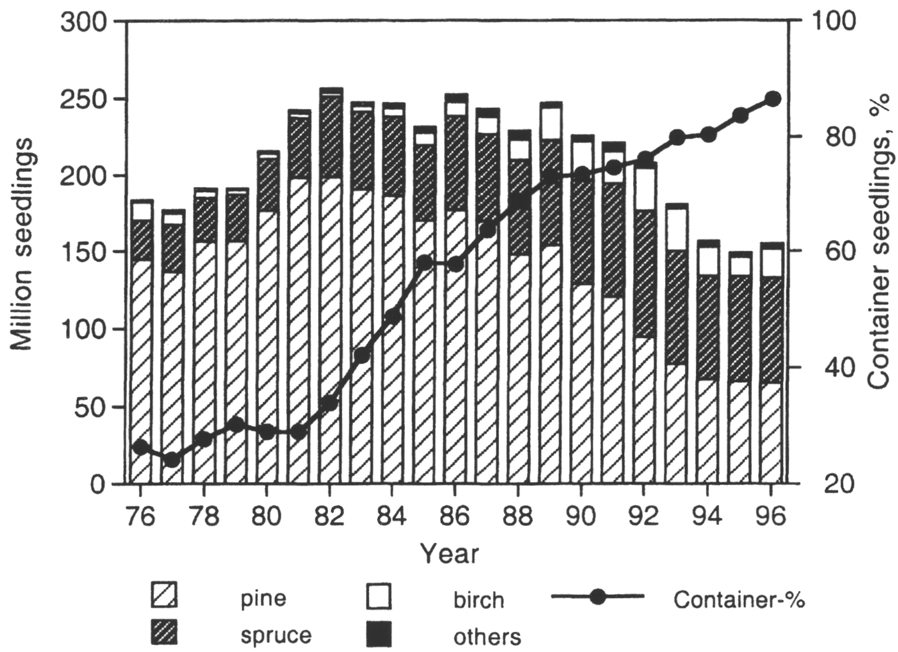


*Figure 1.* Seedling material delivered for planting by tree species and the proportion of container seedlings in years 1976–1996 (Västilä and Herrala-Ylinen 1998).

improve systems of production (Mikola 1957a, b). In the 1960s and 1970s nurseries adopted new technology such as greenhouses, peat as growing medium and increased use of chemical fertilizers (Rikala and Westman 1979). There was still, however, great variation in fertilization practices between nurseries.

During the 1980s and also in the first part of the 1990s there were changes both in stock types and in the tree species produced. In 1996 about 85% of all seedlings were grown in containers, while in the beginning of the 1980s the proportion of container seedlings was about 30% (Figure 1). Especially in production of container seedlings, new technology and practices, such as controlled-release fertilizers (Shaviv and Mikkelsen 1993; Rey 1997) and fertigation with exponential addition rates of nutrients (Timmer and Armstrong 1987; Timmer 1997), could minimize the potential for environmental harm caused by forest seedling production.

The aim was to gather information about actual systems and practices used in the production of seedlings in Finland using a questionnaire-based survey. The use of fertilizers in container and bareroot seedling production, methods of fertilization and methods used to determine the need for fertilization and irrigation are described. The fertilization practices used in production of container seedlings are described in more detail than those used for bareroot seedlings.

## Materials and methods

### *Content of questionnaire*

The data were collected by a questionnaire in 1996. This questionnaire was divided into three parts. The first part was general, dealing with number of seedlings grown and with areas, equipment and growing methods. Most of the questions were multiple choice. There were also spaces available for the respondents to give their own answers and opinions. Nurseries were asked to report the amounts of fertilizers used in production of container and bareroot seedlings in 1996 according to specific fertilizer product. In the first part the information about seedling numbers and amounts of fertilizer used was based on the annual stock inventories of the nurseries.

In the second part of the questionnaire, more detailed questions were asked about cultivation practices and the growing schedule of the largest container seedling lots (later called lot-based information): e.g. sowing dates, period in greenhouse, dates of fertigation and fertilizer doses (g/m$^2$). To transform the amount of fertilizers into nutrient rates, we used the nutrient concentration of products declared in the specifications of fertilizer manufacturers.

In the third part of the questionnaire the use of pesticides as well as disease and insect problems during the 1996 growing season were asked and have been reported elsewhere (Juntunen 2000).

### *Survey population*

In 1996, there were eight nursery companies, which owned 35 nurseries (later called enterprise-owned nurseries). Replies were received from 20 (annual production 4–10 million seedlings) of the 23 nurseries that received the questionnaire. In addition to these enterprise-owned nurseries, there were about 60 family-owned nurseries. Of these family nurseries, ten were asked to complete the questionnaire and eight (annual production 0.1–1.5 million seedlings) replied. Most of those selected were among the biggest seedling producers of the family-owned nurseries.

The survey covered 83% of the total seedling production in Finland, although representation of tree species and stock types varied (Table 1). The representativeness of the questionnaire was estimated by comparing the number of seedlings given in answers to our questionnaire (119 million) with those reported in the official statistics (144.4 million) (Västilä and Herrala-Ylinen 1998). During 1990–1996 family-owned nurseries produced about

*Table 1.* Number of seedlings grown in nurseries surveyed in autumn 1996 and to be delivered during spring 1997. Of the total number of seedlings delivered for planting in 1997, the proportion shipped by nurseries in this study was calculated. N = number of nurseries.

| | | Nurseries in this study | | | All nurseries | |
|---|---|---|---|---|---|---|
| Seedling type and species | N | Growing/ producing area ha | MM seedlings grown | MM seedlings to be delivered in 1997 | MM seedlings delivered for planting in 1997[5] | Percent of Finnish production[6] |
| Pine | | | | | | |
| 1-year | | | | 35.7 | | |
| Total | 24 | 5 | 41.1 | 37.8[3] | 52.6 | 72 |
| Spruce | | | | | | |
| 1-year | | | | 23.5 | | |
| 2-year (1st year) | | | 19.9 | | | |
| 2-year (2nd year) | | | | 31.1 | | |
| Total | 25 | 15 | 74.5 | 54.6 | 50.6 | 108 |
| Birch | | | | | | |
| 1-year | | | | 8.9 | | |
| Total | 22 | 5 | 9.7 | 9.5[3] | 15.8 | 60 |
| Other species, total | 19 | | 2.8 | 2.5 | 4.2 | 60 |
| Container, total | 27 | 25/105[1] | 128.3 | 104.4 | 123.2 | 85 |
| Pine, total | 8 | 10 | | 1.4 | 2.7 | 52 |
| Spruce | | | | | | |
| 4-year | | | | 9.0 | | |
| Total | 11 | 68 | | 10.8[4] | 15.1 | 72 |
| Birch, total | 6 | 25 | | 3.1 | 3.6 | 86 |
| Bareroot, total | 12 | 103/290[2] | | 15.4 | 21.7 | 71 |
| Total container and bareroot | 28 | 128/395[2] | | 119.8 | 144.9 | 83 |

[1] Area covered by container/total area, see text
[2] Area in use/total area
[3] Seedlings older than one year made up the difference between total and one-year-old seedlings
[4] Seedlings younger than four years old made up the difference between total and four-year-old seedlings
[5] Västilä and Herrala-Ylinen 1998
[6] The proportion can be over 100%, because the number of seedlings did not include possible seedling losses and marketing problems for nurseries in spring 1997

ten per cent of the total annual production of seedlings. In this study the proportion of seedlings produced by family-owned nurseries was five per cent.

In Finnish statistics (Västilä and Herrala-Ylinen 1998) only the total number of seedlings delivered annually for planting is presented; neither the amount of stock growing in the nurseries nor the number of seedlings of different ages is reported separately. To differentiate between these two numbers, in this article "growing stock" refers to all seedlings growing in nurseries during the 1996 growing season. "Shipped seedlings" refers to those seedlings that, according to the autumn inventory of the nurseries, were delivered for planting in autumn 1996 or ready for planting in spring 1997.

*Production of seedlings*

The main bareroot product raised in these nurseries was four-year-old Norway spruce (*Picea abies* Karst.) seedlings (Table1). Almost all bareroot silver and downy birch (*Betula pendula* Roth, *Betula pubescens* Ehrh.) seedlings were "plug+1" type. About half of the Scots pine (*Pinus sylvestris* L.) seedlings were "plug+1 to 3" type. The other half were first sown in seed beds and then transplanted.

The nurseries contained 290 hectares of bareroot fields, of which less than half were in seedling production; the largest part was fallow fields (Table 1). The sowing beds covered only about four hectares, and the rest of the area was transplanting fields. All 12 nurseries that produced bareroot seedlings were enterprise-owned. There were five big producers, whose growing area varied from 10 to 25 hectares. The remaining seven nurseries were smaller, each with a growing area of less than five hectares.

The area used to produce container seedlings was 105 hectares, of which 26 hectares were covered with greenhouses and the rest was outdoor growing area. Sixteen of the 19 enterprise-owned nurseries had heated greenhouses, altogether an area of seven hectares. Of the family-owned nurseries, only one had a heated greenhouse. All nurseries had so-called seasonal greenhouses. The fourfold production area compared to the area covered with container trays (25 hectares), in addition to aisles and edges, is explained by the fact that nurseries could keep the same seedling lot at three different places during the growing season. Seedlings were started in greenhouses, from which they were moved to outdoor growing areas and later possibly to winter storage areas.

*Calculations*

The use of fertilizers and nutrients in forest nurseries was calculated both per unit area and per seedling. The area-based values were calculated as nursery means. These values can thus be used to describe the differences between nurseries and also be used in risk analyses concerning nutrient leaching. The mean amount of fertilizer (nutrients) per seedling was weighted by the number of seedlings in the nursery in question. These values describe the total use of fertilizers in the production of forest seedlings, and can be used for life-cycle analysis (Aldentun 1999).

For bareroot stock, only information based on annual inventories (not lot-based) was available. Thus, to compare the fertilization practices for raising bareroot and container stock, the total amounts of fertilizers (nutrients) were divided by the whole production area or the total number of seedlings shipped. This was done separately for bareroot and container stock.

## Results

### *Production practices for container seedlings*

The nurseries used seven different types of containers. Over 70% of the conifer seedlings and about 30% of the birch seedlings were grown in Ecopots (Lännen Inc., Finland, http://www.lannenplantsystems.com). Over 60% of the pine seedlings were grown at high density and in small pots (PS408; V = 75 $cm^3$, 895 pots/$m^2$). In terms of growing density, spruce seedlings varied most. Almost all nurseries in northern Finland (north of 63° N) grew spruce seedlings in smaller pots (PS408), but the nurseries in southern Finland used mostly larger pots (PS508; V = 103 $cm^3$, 620 pots/$m^2$ or PS608; V = 152 $cm^3$, 433 pots/$m^2$). The growing density of birch was lowest, usually less than 200 seedlings per square meter. Almost half of the birch seedlings were grown in hard plastic containers, Plantek25 (V = 380 $cm^3$, 156 pots/$m^2$, Lännen Inc., Finland). All nurseries placed birch trays directly on the ground, but about half of them placed the conifer trays on supports about 15 centimeters above the ground.

All nurseries, with one exception, used commercial Sphagnum peat as growing medium. This peat was supplied to the nurseries in plastic bales. Most of nurseries used special peat for tree seedlings, into which about 0.8 kilogram of fertilizer (16 N, 8 P, 16 K,% and micronutrients) and two kilograms of magnesium-rich limestone (Mg 5%, Ca 20%) per cubic meter of peat was premixed by the supplier, either by Vapo Corp., Finland or Kekkilä Corp., Finland. On an area basis, the growing medium contained 80–100 kg N/ha, depending on container volume and density. Almost half of the N was in the form of ammonium, one-third as slowly degrading ureaformaldehyde and the rest as nitrate (Table 2). The amount of phosphorus (P) premixed into peat for fertilization was 40–50 kg/ha, 75% of this being water-soluble. Only 7% of the nurseries used peat into which controlled-release fertilizers, such as Nutricote® or Osmocote®, were premixed for some seedling lots. One nursery used unpacked peat, into which fertilizer was premixed by the nursery.

*Table 2.* Nutrient concentrations (g/kg fertilizers) of the fertilizers most commonly used in container seedling production.

| | Nutrients g/kg fertilizer | | | | |
|---|---|---|---|---|---|
| | Superex fertilizers[1] | | | | Premixed |
| | 5 | 7 | 9 | 10 | fertilizer ST[2] |
| $NO_3$-N | 90 | – | 72 | 70 | 25 |
| $NH_4$-N | 15 | – | 23 | – | 70 |
| Urea N | 4 | – | 99 | 2 | 5 |
| Ureaformaldehyde N | | | | | 60 |
| N total | 109 | – | 194 | 72 | 160 |
| P total | 40 | 160 | 53 | 50 | 80 |
| K total | 253 | 200 | 200 | 260 | 160 |
| S total | 20 | 31 | 3 | 25 | 3 |
| Mg total | 15 | 23 | 2 | 19 | 55[3] |
| Ca total | | | | | 200[3] |

[1]Other nutrients in Superex fertilizers as mg/kg as chelates: Fe 1800, Mn 970, Zn 230, Cu 140; not as chelates: B 270, Mo 20, Co 10
[2]Other nutrients in peat premixed fertilizer mg/kg: Fe 800 (partly chelated), Mn 300, Cu 200, Zn 100, B 50, Mo 30
[3]In kg magnesium-rich lime

About 75% of the whole greenhouse area and 25% of the whole outdoor growing area were irrigated by mobile booms. The remaining 25% of the greenhouse area was irrigated by fixed systems; and on the remaining 75% of the outdoor area, basal irrigation sprinklers were used. Fertilizers were applied through irrigation systems in liquid form. In outdoor areas, one-third of the nurseries used solid fertilizers in addition to liquid. The solid fertilizers were applied either with tractor-mounted equipment or manually. None of nurseries collected runoff water.

The nurseries began sowing the spruce crops at the end of March and then the pine crops to be planted at the age of one year (Figure 2). Nurseries south of 63° N started sowing pine about one month earlier than nurseries north of 63° N. Spruce crops to be planted at the age of two years were sown at the end of May or the beginning of June. Birch crops were usually sown in the middle of May. The sowing dates varied greatly, however, both between and within nurseries.

Most nurseries grew the first season's spruce seedlings in greenhouses until autumn (Figure 2). The second season's spruce seedlings were grown on outdoor growing areas. The time in the greenhouse varied most for pine (36–94 days) and birch (31–112 days). Some nurseries transported the seedlings

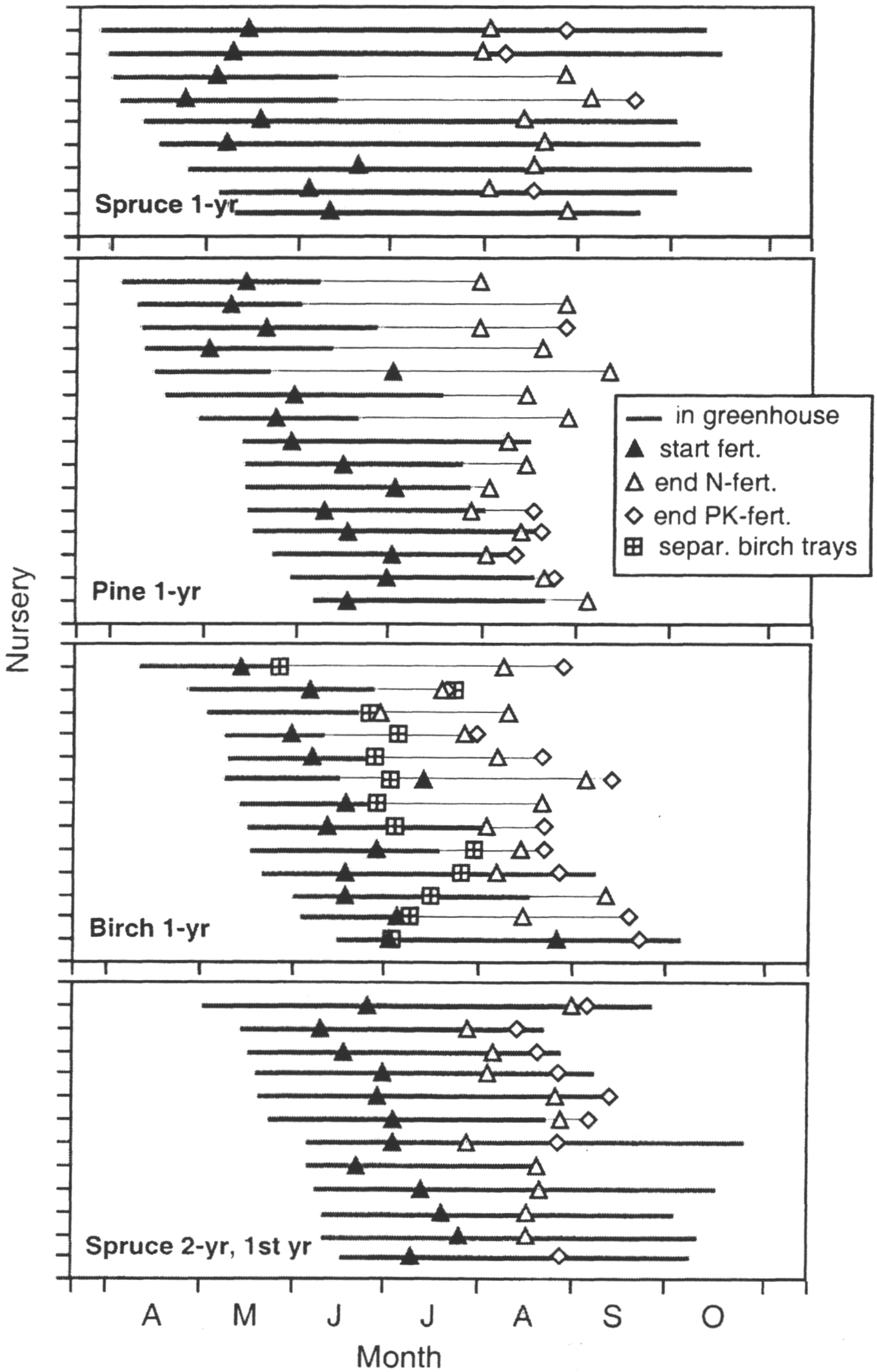


*Figure 2.* Dates of growing practices for different tree species according to lot-based information given by nurseries.

to outdoor growing areas at the beginning of June, while others did so in October.

To increase the flow of air between seedlings, container trays in birch production were separated from each other by 20 cm of free space. On average, the time from sowing to separation was 52 days (range 18–87 days, Figure 2). Separation increased the growing and fertilization area twofold.

*Monitoring seedling irrigation and fertigation*

In container seedling production of pine, spruce and birch, the electrical conductivity (EC) of press-water extracts (= growth-medium solution squeezed physically from peat medium at the actual water content *in situ*, Rikala and Heiskanen 1997) was monitored in all nurseries except for two of the family-owned nurseries. About 75% of the nurseries measured EC once a week during the fertigation period, 20% measured it every second week and the rest once a month. Five nurseries (18%) regularly sent press-water samples and one nursery sent peat samples to a chemical laboratory for nutrient analysis. Sixty per cent of the nurseries considered EC to be the most important factor for determining the need for fertilization, and the rest considered it to be the second most important. The other factors used to evaluate the need for fertilization were growing phase, color and visual appearance of seedlings. Weather conditions were also of some importance.

Half of the nurseries monitored the height of seedlings either once a week or twice a month during the growing period. The height of birch seedlings was monitored most intensively. Foliar nutrients were seldom analyzed. About 20% of the nurseries used foliar analysis if there were problems in propagation.

The need for irrigation was determined by weighing the container trays. About half of the nurseries weighed conifer trays, but only one-third weighed birch trays. Half of the nurseries checked the weight once a week during the growing season, and the rest checked it less often. No direct methods for measuring soil moisture were used. Two-thirds of the nurseries measured the temperature inside the greenhouses daily, but only a few nurseries monitored the temperature on open areas. Half of the nurseries measured precipitation daily. Most of these measurements were carried out manually and only a few nurseries kept records of the measurements.

*Use of fertilizers and nutrients on basis of annual inventories 1996*

The total use of fertilizers was 175 metric tons. Over half of this amount was applied to the bareroot stock. Altogether the nurseries used 21 different fertilizer products to grow bareroot seedlings. The four most commonly used

*Table 3.* Average total N and P use per shipped seedling. The average values were calculated weighted by the number of seedlings in the nursery. Container seedlings were 1- or 2 years old and bareroot seedlings mainly 4 years old.

| Seedling type | N | | | P | | |
|---|---|---|---|---|---|---|
| | (mg per seedling) | | | | | |
| | Premixed fertilizer | Liquid fertilizer | Together | Premixed fertilizer | Liquid fertilizer | Together |
| Container seedling | 18 | 84 | 102 | 10 | 41 | 51 |
| Bareroot seedling | | | 822[1] | | | 237[1] |

[1]In production of bareroot seedlings, base- and top-dressing fertilization could not be separated.

products, however, made up 74% of the total amount. About 66 metric tons were applied to the container stock, mostly in liquid form; and 12 metric tons of fertilizers were premixed into peat growth medium.

In bareroot seedling production the nurseries applied an average of 874 kg/ha of fertilizers, assuming the total amount of fertilizer was applied to the whole production area. The variation between nurseries was, however, great: 242–1735 kg/ha. In container seedling production the comparable mean value was 562 kg/ha of fertilizers (range 83–1330 kg/ha) applied in liquid form. In addition, about 650 kg/ha of fertilizers was premixed into the peat growth medium.

About 5.8 grams of fertilizer per bareroot seedling shipped was applied as base- and top-dressing fertilizer. The nurseries applied about 0.7 grams of liquid fertilizer and 0.1 grams of premixed fertilizer per container seedling shipped. The range of total use in the nurseries studied was 0.12–1.5 grams per seedling.

The amount of N applied to bareroot seedlings was, on average, 129 kg/ha (range 49–332 kg/ha); and the amount of P was 38 kg/ha (range 4–95 kg/ha). In container production the mean amount of N applied in fertigation was 80 kg/ha (range 16–178 kg/ha), and the mean amount of P was 36 kg/ha (range 4–75 kg/ha). The use of nutrients in container and bareroot seedling production could be compared with each other by using the values per seedling shipped (Table 3). Per seedling delivered for outplanting, nurseries used about eight times more N and five times more P for growing a bareroot seedling than for a container seedling.

*Fertigation in container seedling production*

Application of liquid fertilizers was started, on average, one month after sowing; the range between nurseries was, however, great (11–77 days). Starting times did not differ systematically among tree species. On average, nurseries stopped fertilizing on August 20 regardless of species (Figure 2). The average fertigation period for one-year-old spruce was the longest at 95 days and the average period for two-year-old spruce (first season) was the shortest at 54 days.

Fertilizer application rates were about the same throughout the whole fertigation period. During the growing season, the rates varied more between nurseries than within the same nursery. About 80% of the fertilizers applied to container seedlings were Superex fertilizers (Kekkilä Corp.) Almost all nurseries used Superex 9 during the rapid growth phase (Table 2). Some nurseries also used Superex 5 or Superex 10, which contain less N. In the hardening phase, half of seedling lots were fertigated with N-free Superex 7 (Figure 2). For all tree species the mean amount at one application time was about 10 kg N/ha, varying from 3 to 41 kg N/ha.

Depending on tree species, most of the nurseries applied liquid fertilizers 8–12 times during the growing period; but here again, the variation between nurseries was great, from 2–4 times to 21–38 times during the growing period. The mean interval between applications was 5–8 days, i.e. about once a week.

*Nitrogen and phosphorus use on basis of lot-based information*

Depending on seedling type and tree species, the nurseries applied 55–178 kg N/ha and 24–70 kg P/ha (Figure 3). In 1996 the amounts of N and P applied to one-year-old seedlings of different tree species were about the same. On the other hand, the variation between nurseries was large. The nursery with the greatest use of fertilizers applied about six times more N and P than the nursery with the smallest use of fertilizers. In addition to these amounts, about 80–100 kg N/ha and 40–50 kg P/ha were premixed into peat used for growing first-year seedlings. In summary, depending on tree species, for production of container seedlings the nurseries annually applied 145–220 kg N/ha and 80–100 kg P/ha as premixed and liquid fertilizers.

The highest average amount of N applied per seedling was 145 mg per one-year-old birch (Table 4). In addition, loss of N to the free space between separated birch trays was 60 mg per seedling. About 46 mg N was applied for each one-year-old spruce seedling and 75 mg for each two-year old seedling. The smallest mean amount of N, 37 mg per seedling, was applied to one-year-old pine seedlings.

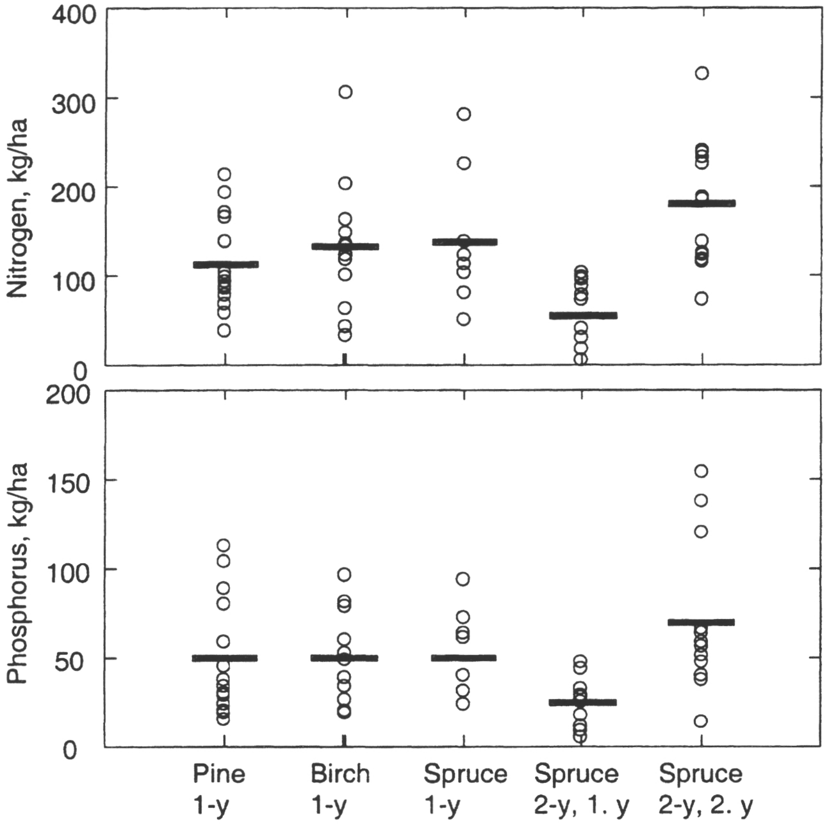


*Figure 3.* Amounts of N and P applied by nurseries to container seedlings as liquid fertilizers. Each dot represents one nursery, and a line indicates the mean amount of the nutrient.

## Discussion

Survey nurseries used 175 metric tons of fertilizers in 1996. Based on this amount, we can estimate the total amount of fertilizers used in Finnish nurseries in 1996 was 200 metric tons. This is one-fourth of the amount used twenty years earlier (Rikala and Westman 1979). The main reasons for the decrease in the use of fertilizers are the decrease in total seedling production and the increased proportion of container production, which means shorter growing time and higher seedling densities.

The use of fertilizers in Finnish nurseries can be compared to the amounts reported by Aldentun (1999) in Sweden. Four Swedish nurseries used 0.8–4.1 grams of fertilizers per seedling shipped. The amounts used are the same order of magnitude as those obtained in the present study. The fertilization practices of container nurseries in different parts of the world have been

*Table 4.* Mean use of N and P per container seedling, based on seedling-lot information. The mean values were calculated weighted by the number of seedlings in the nursery.

| Seedling type | N (mg per seedling) | | | P | | |
|---|---|---|---|---|---|---|
| | Premixed fertilizer | Liquid fertilizer | Together | Premixed fertilizer | Liquid fertilizer | Together |
| Pine, 1-year | 18 | 19 | 37 | 9 | 10 | 19 |
| Spruce, 1-year | 15 | 31 | 46 | 7 | 11 | 18 |
| Spruce, 2-years, 1st year | 24 | 13 | 37 | 12 | 5 | 17 |
| Spruce, 2-years, 2nd year | | 38 | 38 | | 17 | 17 |
| Birch, 1-year | 62 | 85 + 60[2] | 207 | 31 | 29 + 21[2] | 81 |
| Seedling, on the average[1] | 15 | 68 | 83 | 8 | 33 | 41 |

[1]Was calculated by dividing the total nutrient amount by the number of grown seedlings
[2]The first number shows the amount of N or P fertigated to trays and the second number the amount of N or P fertigated to the spaces between container trays, see the text

reviewed (Landis et al. 1989; Donald 1991); but in these reviews the use of nutrients is considered more from the standpoint of the seedlings than of the environment, and little information on the total rates of nutrients per unit area or per seedling has been given for the whole growing season. Interest in such questions first arose in the 1990s (Dumroese and Wenny 1991).

Pine was the principal container-grown crop in Finland in 1976. Nurseries applied, on average, 174 kg N/ha and 80 kg P/ha when fertilizing one-year-old pine container seedlings (Rikala and Westman 1979). In 1996 the respective values were 122 kg for N and 49 kg for P, thus the mean use of nutrients in pine production has decreased. The electrical conductivity of press-water extract from growing medium may have helped the nurseries make their fertilization more precise. In both surveys, however, the use of nutrients varied greatly between nurseries.

In the production of bareroot seedlings, nurseries applied about 130 kg N/ha and 40 kg P/ha annually. The mean amount of N applied in a year was similar to that used 20 years ago (Rikala and Westman 1979); but for growing four-year-old spruce seedlings, the decrease in mean amount of P has been about 30 kg/ha. The amount of N is quite similar to that which nurseries in the United States have applied annually to bareroot seedlings (van den Driessche 1984; South and Zwolinski 1996) and what has been recommended in Great Britain (Proe 1994). On the other hand, the amounts of P applied differ: nurseries in the southern United States apply, on average, only 25 kg P/ha (South and Zwolinski 1996), while nurseries in the Northwest apply about 70 kg P/ha (van den Driessche 1984).

Nurseries included in this 1996 study applied, on average, larger amounts of nutrients to nursery areas than were applied to agricultural areas in Finland. On the basis of sold fertilizers and agricultural crop area, the average application was about 90 kg N/ha and 16 kg P/ha to agricultural areas during 1994–1997 in Finland (Tietovakka 1999). This is supported by data concerning changes in cultivation practices in Finnish agriculture since Finland joined the European Union (Rekolainen et al. 1999; Granlund et al. 2000). In particular, the amounts of P applied to agricultural areas have decreased since that time (Rekolainen et al. 1999).

The coverage of the survey was good, over 80% of the Finnish seedling production in 1996. However, the results are based on only one year, which does not give information about results in different types of weather. Weather conditions influence nursery practices and use of fertilizers, e.g. rain may leach nutrients from the growing medium to the ground and increase the need for fertilization. In July 1996, when fertigation of seedlings was most intensive, and birch and some pine seedling lots were moved out of the greenhouses, at most weather stations in Finland it rained 30–40 mm more than is normal for July (60–80 mm) (Ilmastokatsaus 1996).

If we look at fertilization from the environmental standpoint, the production of bareroot seedlings is similar to agricultural production. Fertilizers are applied directly onto the ground, from which, during rainy periods, nutrients run off either to the surface or to the ground water. Production of container seedlings, on the other hand, is more like horticultural production. Seedlings are started in greenhouses and, depending on seedling type, continue to grow there for two to six months. In container seedling production the nutrients reaching the ground consist of nutrients that leach from the growing medium and nutrients applied directly to aisles and other empty space around the container blocks.

The Finnish nurseries used peat premixed with fertilizer, which means that at the time of sowing the nutrient concentration of the peat was high. Greater nutrient leaching may result from higher nutrient concentrations in the growing medium (van der Boon and Niers 1983). The need to keep the peat surface wet to promote seed germination may lead to overirrigation and leaching of nutrients. If fertilizers were not premixed into peat, there would be no risks for leaching of nutrients before fertigation.

The probability of leaching due the heavy rains or overirrigation is much higher if nutrients are applied periodically in large doses rather than applied constantly in small doses. The third method, exponential fertilization, which has been tested in container tree nurseries (Timmer and Armstrong 1987; Timmer 1997), would decrease both the build-up of salinity and leaching of nutrients. Both periodic and constant methods were in use among the Finnish nurseries studied here.

In the greenhouse, leaching depends a lot on how well the grower manages irrigation, e.g. the type of irrigation system and frequency of irrigation (Dumroese et al. 1995). Mobile booms irrigate in short cycles and more evenly and may reduce the volume of leaching water compared to continuously irrigating fixed systems (Fare et al. 1994). In Finland, nurseries try to avoid overirrigation, and they do not flush nutrients from the growing medium by using the replacement method (Mullin and Hallet 1983). About half of the nurseries tried to keep the water content of containers at optimum level (water volume = 40–50% of the container volume) by weighing the containers.

On outdoor growing areas, leaching depends more on weather conditions, especially on amount of precipitation (van der Boon and Niers 1983). In Finnish nurseries the first season's spruce seedlings and also some pine seedling lots were kept in greenhouses until September or October. The longer the seedlings are in the greenhouse the smaller is the risk of nutrient leaching. Only a few nurseries grew more than one crop per year in a greenhouse, which meant that many nurseries were not in a hurry to move seedlings onto open growing areas.

On the questionnaire the use of fertilizers was asked in two ways: total use during the 1996 growing season according to annual inventories and use in growing of certain seedling lots. These two approaches gave different results (Table 4). Apparently, on the basis of values obtained from lot-based information, it is not possible to calculate the total use. The amount of fertilizer that nurseries applied to empty spaces around container blocks explains part of the difference between these two values. Dumroese et al. (1995) calculated that in their nursery with a mobile boom system 12.5% (by volume) of the irrigation water was not sprayed on the seedlings. On outdoor growing areas most nurseries applied liquid fertilizers through sprinklers, which means that the volume of irrigation water (nutrients) not sprayed on the seedlings could have been even greater than in the greenhouses.

For environmental reasons, nurseries must try to optimize the use of fertilizers. One method for doing this could be to use nutrient balance sheets, which could be calculated as the difference between nutrient uptake (content) of seedlings and the amount of the nutrient given in fertilization. In this way the efficiency of fertilization could be evaluated and the nutrient inputs and outputs in a nursery be estimated (Dumroese and Wenny 1991; Landis 1997). To make these calculations, however, the nutrient content of grown seedlings and that of the growing medium must be known. Although in seedling production the fertilization cost is marginal (South and Zwolinski 1996), optimization could also reduce the costs of seedling production.

The applied nutrient amounts varied considerably between nurseries, even for growing the same type of seedling stock. Apparently, all the nurseries surveyed produced seedlings that fulfil the Finnish quality requirements for commercial seedlings (see the requirements in Rikala 2000). Presumably, some growers could have applied less nutrients than they did without reducing the quality of their seedling stock. Although the reasons for differences in fertilization cannot be analyzed by this kind of questionnaire; the survey gives nurseries the possibility to compare their amounts of nutrients applied with the amounts used in other nurseries and could provide the impulse for evaluation and development of fertilization methods and systems.

## Conclusions

The change from bareroot to container seedlings and the decrease in seedling production has reduced the total amount of fertilizers used in Finnish forest nurseries. On the other hand, the amounts of nutrients applied per unit area were higher in container seedling production than in bareroot seedling production. However, less of the total amount is applied directly onto the ground in container seedling production than in bareroot seedling production. Nurseries should try to optimize the use of nutrients, and carefully control the leaching of water through containers to the ground. It is also essential in container seedling production to reduce the amount of fertilizers applied to spaces where there are no seedlings.

## Acknowledgements

We gratefully acknowledge the cooperation of the personnel of the forest nurseries, who made this study possible by answering the extensive questionnaire. We thank Dr. H. Heinonen-Tanski, Dr. H. Smolander, T. Hammar, M.Sc. and three anonymous referees for valuable comments on the manuscript, and Dr. J. von Weissenberg for revising the English language.

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# II

# Use of Pesticides in Finnish Forest Nurseries in 1996

Marja-Liisa Juntunen

**Juntunen, M-L.** 2001. Use of pesticides in Finnish forest nurseries in 1996. Silva Fennica 35(2): 147–157.

In 1996 a questionnaire on seedling production and use of pesticides was sent to 33 forest nurseries in Finland. Twenty-eight nurseries answered the questionnaire; thus the survey covered about 80% of the Finnish production of forest seedlings. According to this study, the Finnish nurseries together are using about 1000 kilograms of pesticides (as active ingredient, a.i.) annually. The most used herbicide was terbutylazine (Gardoprim-Neste®), and half of the total amount of fungicide used was chlorothalonil (Bravo 500®). Three fourths of the insecticide products had permethrin as the active ingredient. The nurseries applied, on average, 1.7 kg pesticides (a.i.)/ha annually, although the amount varied considerably between nurseries. In production of container seedlings the highest mean amounts of pesticides were applied to pine seedlings (9.5 kg/ha) and the lowest to spruce seedlings (0.9 kg/ha). To the fields of bareroot seedlings the nurseries applied, on average, 3.9 kg pesticides (a.i.)/ha. Mean amounts of pesticide (a.i.) per 1000 seedlings grown in containers were almost the same for birch and pine production, 1.6 and 1.7 grams, respectively; for production of spruce seedlings the comparable values were less than 0.5 grams. For production of bareroot seedlings the nurseries used about four times more pesticides than for container seedlings.

**Keywords** fungicides, herbicides, insecticides, seedlings, survey study
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**Received** 31 March 2000 **Accepted** 11 May 2001

## 1 Introduction

During the 1980s and the beginning of the 1990s, production of container seedlings to a large extent replaced production of bareroot seedlings in Finland. In 1996 about 85% of all nursery seedlings were grown in containers (Västilä and Herrala-Ylinen 1998). New nursery technology and systems of production have decreased the growing time for nursery seedlings from four years to one year. In spite of the short growing time needed to produce seedlings, nurseries still have problems with pests (Uotila 1995, Lilja et al. 1997).

Finnish forest nurseries try to control seedling losses due to weeds, diseases and insects by using good hygiene and culturing practices. Although interest in using non-chemical methods of control in pest management has increased among forest nurseries, chemical control is still needed to diminish seedling losses (South 1991, 1995, Lilja et al. 1997). Use of pesticides may, however, also have an impact on the environment (Landis et al. 1991).

Kangas et al. (1980) estimated that at the end of the 1970s Finnish nurseries used at least 18 000 kilograms of pesticides (a.i.) annually. However, no information has been available concerning the recent use of pesticides in forest nurseries in Finland. From the annual statistics on amounts of pesticides sold, it is not possible to separate the amounts sold to forest nurseries from those sold to other consumers of such products. Nor are the practices used by the nurseries for pest control well known.

In 1996 information about the actual systems and practices used by nurseries to grow seedlings was gathered by using a questionnaire-based survey. The questionnaire was divided into three parts. The general questions in the first part of the questionnaire dealt with amounts and areas of production, equipment and growing methods including use of pesticides and fertilizers. In the second part of the questionnaire more detailed information was collected concerning cultural practices and the growing schedule of some of the largest seedling lots. In the third part of the questionnaire the nurseries gave information about disease and insect problems in their nursery during the 1996 growing season. The growing practices of the nurseries and the use of fertilizers in the nurseries (Juntunen and Rikala 2001) as well as disease and insect problems (Juntunen 2000) have been reported elsewhere.

This article deals with the use of pesticides in production of container- and bareroot seedlings. The chemical-control practices used in production of container seedlings are described in more detail than those for bareroot seedlings. Both area- and seedling-based values for use of herbicides, fungicides and insecticides in production of container seedlings of different tree species are presented.

# 2 Materials and Methods

## 2.1 Questionnaire and Nurseries

The use of pesticides was asked in two ways on the questionnaire: total use during the growing season and use in growing certain seedling lots. First, nurseries gave the amounts and trademarks of pesticides used on different target sites and areas, e.g. for container- and bareroot seedlings, for open areas without containers, fallow fields and edges. Second, the nurseries gave such information as the application dates, trademarks of the pesticides used, and the doses used per hectare in growing each special seedling lot.

The questionnaire was sent to 33 forest nurseries (at latitudes 59–66°N) in Finland. Twenty-eight nurseries returned the completed questionnaire. Of these twenty were large nurseries (annual production 4–10 million seedlings) owned by commercial enterprises and eight were smaller (annual production 0.1–1.5 million seedlings), family-owned nurseries. The mean size of each enterprise-owned nursery was 30 hectares and that of a family-owned nursery was less than one hectare.

About half of the total area of the nurseries consisted of bareroot fields (290 ha). However, less than half of the bareroot fields were in seedling production (108 ha); the largest part was fallow fields. Only 12 enterprise-owned nurseries produced bareroot seedlings, but all produced container seedlings. The family-owned nurseries, on the other hand, grew only container seedlings. The area used to produce container seedlings was 105 hectares, of which 26 hectares were greenhouses and the rest was outdoor growing areas. Nurseries estimated that a large part (144 ha) of their area consisted of yards (54 ha), roads (46 ha) and edges (44 ha).

Areas used to produce container seedlings were covered. As a covering material, asphalt or a layer of stone chips (10–30 cm) or sand (20–30 cm) was used. In eight nurseries the bottoms of the greenhouses were made from asphalt, but only five nurseries had covered more than 70% of the greenhouse area. The most commonly used material was sand, which was used by 16 nurseries to cover over 70% of their greenhouse area. Outdoor growing areas were also usually covered with sand.

### 2.2 Representativeness of Results and Production of Nurseries

This survey covered about 80% of the total seedling production in Finland. The numbers of produced seedlings reported by nurseries (119 million seedlings) were compared to those given in official statistics (144 million seedlings) (Västilä and Herrala-Ylinen 1998). The actual coverage depended on tree species and stock types (Juntunen and Rikala 2001). During 1990–96, family-owned nurseries produced about ten per cent of all seedlings produced annually in Finland, even though the proportion of family-owned nurseries in this study was only five per cent.

In this article 'produced seedlings' refers to those seedlings that, according to the autumn inventory of the nurseries, were delivered for planting in autumn 1996 or were ready for planting in spring 1997. 'Growing stock' refers to all seedlings growing in the nurseries during the 1996 growing season. For container seedlings, the numbers of grown and produced seedlings are very similar, because over 90% of all pine and birch seedlings were delivered for planting as one-year-old seedlings. The only difference was in the number of two-year-old spruce seedlings. About 57% of the container-produced spruce seedlings were delivered for planting at the age of two years and the rest (43%) at the age of one year (Juntunen and Rikala 2001). The nurseries gave such detailed information about the production of container seedlings that the use of pesticides could also be calculated for grown seedlings.

On the other hand, for production of bareroot seedlings there was not enough information available to calculate the use of pesticides separately for each growing year. About 70% of the bareroot seedlings were spruce, 20% were birch and the rest were pine. In terms of age, the greatest number was four-year-old spruce seedlings (Juntunen and Rikala 2001). The use of pesticides could be calculated only per number of seedlings produced. The values per number of seedlings produced are valid if the numbers of different seedling types produced do not vary markedly between years.

### 2.3 Calculations

The use of pesticides in forest nurseries was calculated either per unit area or per seedling. The mean area-based values were calculated as nursery averages. Zero values, which meant that pesticides were not used, were not included in the mean values. Thus the per area values can be used to describe the differences between nurseries; and if seedlings were sprayed, the mean value described the real load on the nursery environment associated with the applications.

The area-based values were transformed to seedling-based values with the help of growing densities. The mean seedling-based values were calculated weighted by the numbers of seedlings produced by nurseries; and the zero values were included because, if these values are used in life-cycle analyses (Aldentun 1999), this is related to information about the total production of forest seedlings.

## 3 Results

### 3.1 Number of Pesticide Products Used

In 1996 the nurseries surveyed in this study used a total of 39 different pesticide products, of which 17 were herbicides, 12 fungicides and 10 insecticides. One nursery used, on average, eight different products. Two family-owned nurseries had sprayed with only one product and another two with two products. Six nurseries had used more than 12 products for chemical control. The maximum number of products, 17, was used in two nurseries. Although the number of products was quite large, in kilograms (as a.i.) the use of most products was very small. The six most commonly used products, two from each pesticide group, made up 76% of the whole amount.

The largest number of products was used in growing of pine seedlings (Table 1). For growing birch, all nurseries had used fungicides, about half had used insecticides and none had used herbicides. Some nurseries grew container spruce seedlings without pesticides. For growing spruce, most of the nurseries used, on average, one fungicide and one insecticide product.

**Table 1.** Number of pesticide products used in growing different species of container seedlings in 1996. The use of permethrin products is excluded from the results of all but two nurseries, because the other nurseries sprayed in spring 1997. n=number of nurseries.

| Number of products | Number of nurseries according to detailed growing information | | | | |
|---|---|---|---|---|---|
| | Pine, 1-y n=16 | Birch, 1-y n=13 | Spruce, 1-y n=9 | Spruce, 2-y 1st year n=13 | Spruce, 2-y 2nd year n=15 |
| None | | | 1 | 3 | 5 |
| 1 | | 2 | 5 | 6 | 5 |
| 2–3 | 9 | 7 | 1 | 4 | 2 |
| 4–5 | 5 | 3 | 2 | | 3 |
| 6–7 | 2 | 1 | | | |

**Table 2.** Number of pesticide applications to container seedling growing stock in 1996. n=number of nurseries.

| Number of applications | Number of nurseries according to detailed growing information | | | | |
|---|---|---|---|---|---|
| | Pine, 1-y n=16 | Birch, 1-y n=13 | Spruce, 1-y n=9 | Spruce, 2-y 1st year n=13 | Spruce, 2-y 2nd year n=15 |
| None | | | 1 | 3 | 5 |
| 1–5 | 5 | 9 | 6 | 10 | 8 |
| 6–10 | 6 | 3 | 2 | | 1 |
| 11–15 | 3 | | | | 1 |
| 15–20 | 2 | 1 | | | |

### 3.2 Frequency and Timing of Applications

The number of pesticide applications was greatest for growing pine (Table 2). The variation between nurseries was high; during the whole growing season one nursery sprayed 19 times and another only three times. The maximum number of applications used for growing one birch seedling lot was 19 and the minimum was two. Spruce seedlings were sprayed one to three times during the growing season.

The chemical control season was longest for growing pine. One nursery carried out the first pesticide application in April and six nurseries made the last applications in November. Almost all nurseries that grow pine applied fungicides from July to October, while most of those that grow birch applied fungicides from July to September. For growing spruce the fungicide applications were concentrated to October, when the nurseries sprayed in an attempt to prevent snow blight. About half of the nurseries, regardless of tree species, prevented insect damage with chemical control in June and July. Only a few nurseries used chemical control in an attempt to prevent weeds in containers. These applications were most frequent in second-year spruce stands in May, at which time three nurseries applied herbicides.

### 3.3 Amounts of Pesticides Used

Altogether, the nurseries used 662 kilograms of pesticides (as a.i.). These pesticides included herbicides (42%), fungicides (40%) and insecticides (18%) (Tables 3–5). One enterprise-owned nursery gave no information about use of pesticides, and another gave only information about production of bareroot seedlings. One enterprise-owned nursery informed only about the total use, but not the proportions used on different target sites.

During the 1996 growing season the nurseries had applied 17 different herbicide products. The most used herbicide was terbutylazine (Gardoprim-Neste®), which nurseries used, in particular, to control weeds in seedling crops (bareroot and container) (Table 3). Glyphosate (Roundup®) was used almost as much as terbutylazine, mostly for chemical control of weeds on areas without seedlings. Quinoclamine (Mogeton®) was sprayed on container seedlings to prevent the growth of liverworts.

The four most commonly used products accounted for three-fourth of the total use of herbicides (Table 3). Other products were used for chemical control of weeds on bareroot fields and also on empty outdoor areas. However, the amount of any single product used was less than five kilograms (a.i.). Herbicides other than terbutylazine and glyphosate were sprayed more on an experimental scale than on an operational scale.

About half of the total amount of herbicides

**Table 3.** Total use of different herbicides (active ingredient and trade name) as a.i. at different nursery sites. n = number of nurseries that had used the herbicide.

| Herbicide | Container seedlings | | Bareroot seedlings | | Outdoor areas | | Fallow fields | | Edges | | Total[a)] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | kg | n=25 | kg | n=10 | kg | n=25 | kg | n=12 | kg | n=25 | kg | n=27 |
| Terbuthylazine (Gardoprim-Neste®) | 19.4 | 11 | 57.0 | 9 | 17.5 | 2 | | | 12.3 | 3 | 122.7 | 17 |
| Glyphosate (Roundup®) | 2.9 | 1 | 12.2 | 5 | 23.7 | 6 | 33.2 | 9 | 14.8 | 11 | 87.8 | 18 |
| Quinoclamine (Mogeton®) | 14.3 | 8 | | | | | | | | | 14.3 | 8 |
| Glufosinate-ammonium (Basta®) | | | | | 0.2 | 1 | 6.0 | 1 | 4.0 | 2 | 10.2 | 2 |
| Others (13 products) | 0.7 | 2 | 17.8 | 6 | 16.2 | 4 | | | 5.9 | 5 | 42.2 | 13 |
| Total | 37.3 | 13 | 87.0 | 10 | 57.6 | 9 | 39.2 | 9 | 37.0 | 15 | 277.2 | 21 |

a) One nursery gave only the total use, not the proportions used at different target sites.

**Table 4.** Total use of different fungicides (active ingredient and trade name) as a.i. in production of container and bareroot seedlings. n = number of nurseries that had used the fungicide.

| Fungicide | Container seedlings | | Bareroot seedlings | | Total[a)] | |
|---|---|---|---|---|---|---|
| | kg | n=25 | kg | n=10 | kg | n=27 |
| Chlorothalonil (Bravo®) | 86.5 | 19 | 41.5 | 7 | 136.9 | 21 |
| Maneb (Maneba®) | 19.0 | 7 | 27.8 | 6 | 46.8 | 10 |
| Tiram (Tirama 50®) | 13.8 | 7 | | | 13.8 | 7 |
| Propiconazole (Tilt 250 EC®) | 8.1 | 16 | 9.1 | 8 | 24.9 | 19 |
| Benomyl (Benlate®) | 6.5 | 10 | | | 10.9 | 11 |
| Triadimefon (Bayleton®) | 3.2 | 15 | 3.1 | 5 | 8.3 | 16 |
| Others (6 products) | 22.3 | 9 | 5.0 | 2 | 26.1 | 11 |
| Total | 159.4 | 23 | 86.5 | 8 | 267.7 | 25 |

a) One nursery gave only the total use, not the proportions used at different target sites.

used was applied on sites without seedlings, such as outdoor areas, fallow fields and edges, i.e. not on bareroot or container stock. Of the 50% used on growing stock, the majority (70%) was used on bareroot fields and the remainder on container seedlings.

The nurseries used a total of 12 different fungicide products. Two thirds of the total amount of fungicides was used in production of container seedlings (Table 4). Two nurseries, both of which produced only bareroot spruce seedlings, sprayed no fungicides on their bareroot fields. The most used fungicide was chlorothalonil (Bravo 500®), which accounted for half of the total amount of fungicide used.

Nurseries used 10 different insecticide products, three of which contained permethrin (Table 5). Almost 80% of the total amount of insecticides were products that had permethrin as the active ingredient. To prevent seedling damage by the pine weevil in the forest after planting, seedlings were sprayed with permethrin products some days before they were shipped to the forest for planting, usually in spring. All nurseries located at 62°N or farther south sprayed pine and spruce seedlings with permethrin products.

**Table 5.** Total use of different insecticides (active ingredient and trade name) as a.i. in production of container and bareroot seedlings. n=number of nurseries that had used the insecticide.

| Insecticide | Container seedlings | | Bareroot seedlings | | Total[a)] | |
|---|---|---|---|---|---|---|
| | kg | n=25 | kg | n=10 | kg | n=27 |
| Permethrin (Gori 920®, F-permetriini®, Ambush®) | 75.4 | 11 | 8.8 | 3 | 92.4 | 13 |
| Dimethoate (Roxion®, R-Dimetoaatti®) | 4.7 | 11 | 4.8 | 3 | 9.6 | 12 |
| Oxydemoton-methyl (Metasystox R®) | 4.0 | 4 | 3.4 | 3 | 14.0 | 7 |
| Cypermethrin (Ripcord®) | 0.4 | 9 | 0.4 | 2 | 1.0 | 9 |
| Others (3 products) | 0.2 | 3 | 1.4 | 2 | 1.6 | 5 |
| Total | 84.7 | 20 | 18.8 | 6 | 118.6 | 24 |

a) One nursery gave only the total use, not the proportions used at different target sites. Two nurseries gave no specific amounts, only indicating that they had used a little of the insecticide in question.

Products other than those containing permethrin were used to prevent insect damage during the summer. The nurseries included in this study used only about 25 kilograms of these other insecticides (a.i.), and the amounts used per nursery were small. Dimethoate (Roxion®, R-Dimetoaatti®) was the most used insecticide in terms of amount as well as number of nurseries.

Three nurseries, two enterprise-owned and one family-owned, used no insecticides in production of container seedlings. For production of bareroot seedlings the respective number of nurseries was four out of ten. Over 80 per cent of the insecticides were used in production of container seedlings (Table 5).

One estimate of annual pesticide use can be calculated by dividing the total quantity of pesticides by the area of the nursery. The amounts used varied between nurseries; southern enterprise-owned nurseries used 1.8 kg pesticides (a.i.) per hectare, northern enterprise-owned nurseries used 1.2 kg and family-owned nurseries used 1.5 kg. The best explanation for these differences was insecticide applications against pine weevil in the southern nurseries.

The nurseries applied, on average, 3.9 kg of pesticides (a.i.) per hectare to the fields of bareroot seedlings. The variation between nurseries was 0.6 to 13.2 kg/ha. The highest mean doses of herbicides were sprayed on the edges (2.4 kg/ha), the next highest on outdoor areas without seedlings (1.2 kg/ha) and the smallest amount on fallow fields (0.5 kg/ha). These values are, however, imprecise because the questionnaire did not ask about exact areas of application.

According to the seedling lot information for production of container seedlings, all nurseries used fungicides for growing birch and pine, and about half of the nurseries used fungicides for growing spruce. The largest doses per hectare were applied to the pine seedlings, for which the mean value was 8.4 kg fungicides per hectare as a.i. (Fig. 1). The mean amounts of fungicide used for production of birch (1.3 kg/ha) and spruce (0.9–1.3 kg/ha) seedlings were about the same.

Insecticides were also sprayed most on pine seedlings (2.5 kg/ha). The permethrin applications, which two nurseries carried out already in autumn on the monitored seedling lot, explain the high mean value. In Fig. 1 the amounts of permethrin used are marked on the bars with a dotted line. Otherwise, the difference in insecticide doses between tree species was not as great as the difference in fungicide doses. Herbicides were used in large amounts only on second-year spruce stocks (3 kg/ha).

In terms of total amounts of pesticides, the variation between nurseries was great (Fig. 1). However, there was no tendency for those nurseries that used large amounts of pesticides, e.g. in pine production, also to do so for spruce production. Pesticides were applied in accordance with the recommended rates given on the product labels. Only one nursery sprayed regularly with insecticide throughout most of the growing season.

Another estimate of pesticide usage can be expressed as amount used to produce 1000 shippable seedlings. The values per 1000 produced seedlings makes it possible to compare container-

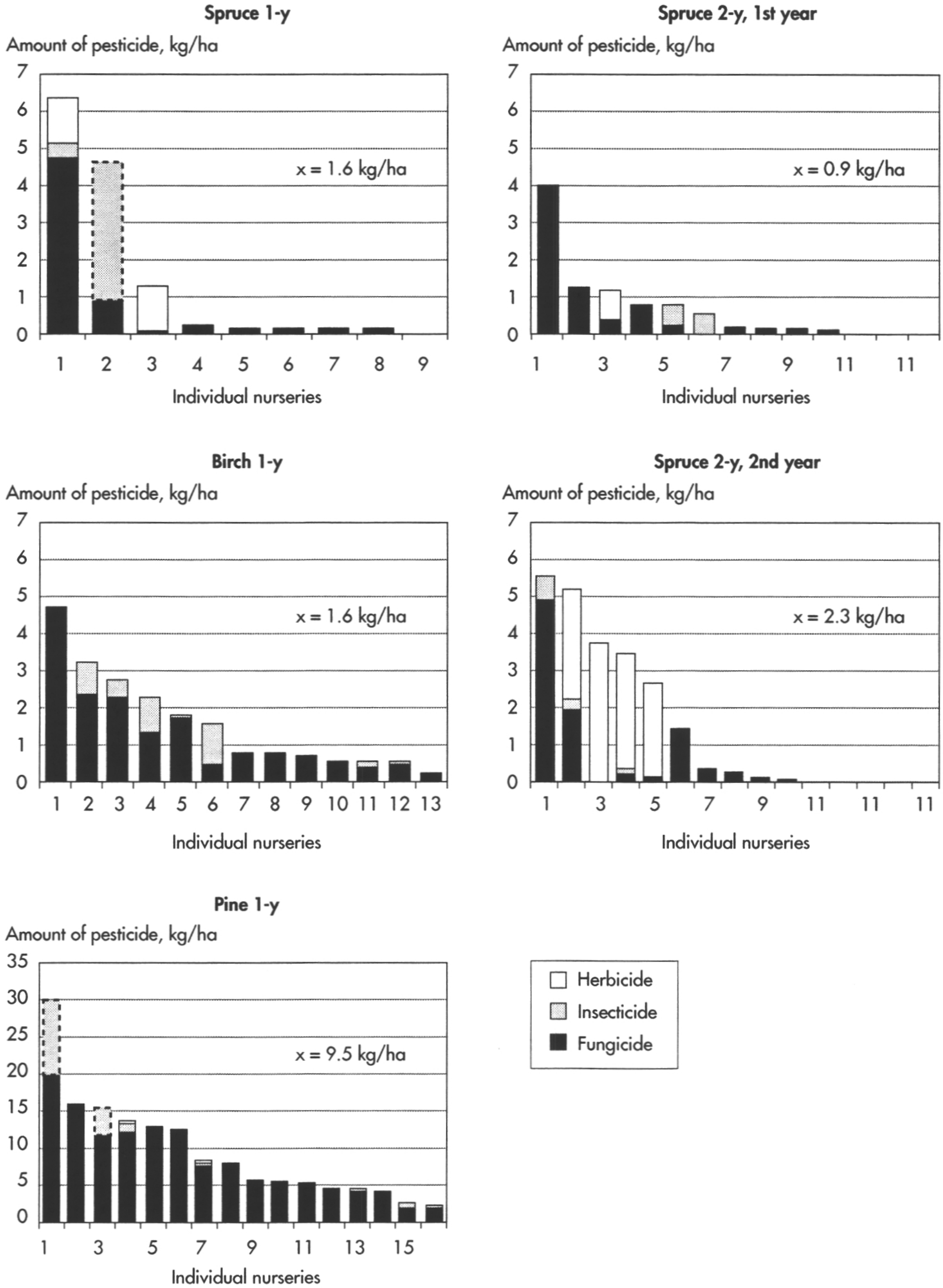


**Fig. 1.** Use of pesticides per unit area according to the detailed growing information. Zero values are not included in the mean. The nurseries are arranged in decreasing order according to amounts of pesticides, which means that number one does not represent the same nursery in all seedling lots. The amounts of permethrin applied by two nurseries in autumn are marked on the bars with a dotted line.

**Table 6.** Comparison of pesticide use in production of container and bareroot seedlings. The means, which were weighted by amount of production of the nurseries, were calculated as grams of active ingredient per 1000 seedlings produced.

| | Container grams/1000 seedlings | Bareroot grams/1000 seedlings |
|---|---|---|
| Herbicides to seedlings | 0.3 | 5.6 |
| Herbicides to outdoor areas | 0.6 | |
| Herbicides to fallow fields | | 2.3 |
| Fungicides to seedlings | 1.6 | 5.6 |
| Insecticides to seedlings | 0.9 | 1.2 |
| Total | 3.4 | 14.7 |

**Table 7.** Mean use of pecticides per 1000 container seedlings in different seedling stocks during the 1996 growing season. These results are based on the detailed growing information. When mean values were calculated, they were weighted by the number of seedling produced by the nursery, and zero values are also included.

| | Active ingredient grams per 1000 seedlings | | | | |
|---|---|---|---|---|---|
| | Number of nurseries | Use of fungicides | Use of insecticides | Use of herbicides | Total |
| Birch 1-y | 13 | 1.39 | 0.19 | 0.00 | 1.58 |
| Pine 1-y | 16 | 1.40 | 0.30 | 0.002 | 1.70 |
| Spruce 1-y | 9 | 0.19 | 0.27 | 0.05 | 0.51 |
| Spruce 2-y, 1st year | 13 | 0.12 | 0.01 | 0.01 | 0.14 |
| Spruce 2-y, 2nd year | 15 | 0.13 | 0.01 | 0.11 | 0.25 |
| Seedling[a)], on average | 25 | 1.23 | 0.65 | 0.28 | 2.16 |

[a)] Based on total number of seedlings and on total use of pesticides (from annual inventories).

and bareroot seedlings (Table 6). The nurseries used about four times more pesticides for growing bareroot seedlings than for growing container seedlings.

The seedling-based values for different tree species were obtained from the detailed growing information (Table 7). In birch production the nurseries separate containers from each other so that there are about 20 centimeters of free space between containers. The free spaces increase the flow of air between containers and prevent diseases. This separation increases the required growing area about twofold. Although the nurseries separated the containers on very different dates during the summer, only 15% of all applications were made before separation. In our calculations the pesticide values for 1000 seedlings were therefore not twofold but 1.85 fold.

The difference between values calculated on the basis of detailed growing information and those calculated from the total use of pesticide is large (Table 7). Evidently the values obtained from detailed growing information underestimate the actual use.

# 4 Discussion

The nurseries included in this study used a total of 662 kg of pesticides (a.i.) during the 1996 growing season. If it is estimated that the rest of the nurseries in Finland used the mean amount of pesticide, the total use of pesticides in the whole country that year was about 1000 kilograms. If this amount is compared with the estimation of 18 000 kilograms made at the end of the 1970s (Kangas et al. 1980), pesticide use has decreased tremendously. The main reasons for the decrease in the use of pesticides are the increased proportion of container-seedling production, shorter growing time and the decrease in total production area.

In Finland the number of seedlings produced has also decreased since the 1980s, from 210–250 million seedlings to 150–180 million seedlings. In particular, the production of pine has decreased. According to the survey, the largest amounts of pesticides were used in pine production. The change in pesticide products may also have decreased their use. To obtain the desired effect with new active ingredients, the doses required are usually lower than with the old ingredients.

In 1996 a total of 956 metric tons of pesticides (a.i.) were sold in Finland. Of this amount, 21 metric tons were for forest protection (Hynninen and Blomqvist 1997). Forest nurseries are using about 5% of the amount used in the forest sector and about 0.1% of the total amount of pesticide used in Finland. Although in terms of environmental effects, the nurseries are only a small point source of pesticides, they may be important locally, because some nurseries are located on ground water areas.

In Sweden, Persson (1992) examined the pesticide use of 15 nurseries in 1991 and found that use of pesticides depended on the size of the nursery. The large nurseries (production over 20 mill. seedlings) used, on average, 2.5 grams pesticide (a.i.) per 1000 seedlings and small ones (production less than 5 mill.) used 5.1 grams per 1000 seedlings. In Finland small, family-owned nurseries carried out fewer applications and used fewer products in production of seedlings than large enterprise-owned nurseries did. The small assortment of seedling types, growing of spruce and the young age of the nurseries may be possible explanations for the modest use of pesticides among family-owned nurseries.

In both Sweden and Finland the variation in pesticide use between individual nurseries was great. The mean values in Persson's (1992) and this study were, however, very similar. The use of pesticides per 1000 grown seedlings varied depending on seedling type and tree species. The magnitude of the values is, however, the same for all species of container seedlings, and this information is important when life-cycle analysis is made for wood-based products (Aldentun 1999).

The bareroot nurseries in the southern United States had applied, on average, about 2.0, 2.9 and 1.7 kg a.i./ha/crop of herbicides, fungicides and insecticides, respectively (South and Zwolinski 1996). On the basis of these values, the average use of pesticides per unit area in these nurseries was about twice the amount used on Finnish bareroot fields.

On the basis of the total area of nurseries and their use of pesticides, the nurseries applied, on average, 1.7 kg pesticides (a.i.)/ha annually. In Finland the use of pesticides on agricultural areas is also calculated by the same method. From 1990–1994 the estimated value was found to vary between 0.7 and 1.0 kg pesticides (a.i.)/ha (Laitinen et al. 1996). In Europe the highest mean use has been 10–17 kg/ha annually in Belgium and the Netherlands; in many countries the smallest mean use has been about two kilograms per hectare (Brouwer et al. 1994)

The mean amounts of pesticide use were greatest for pine seedlings (9.5 kg/ha) and smallest for spruce seedlings (0.9 kg/ha). Also in agricultural use, the species grown affects the use of pesticides. For cereals the annual rate is estimated to be about 2.6 kg/ha (Laitinen et al. 1996). According to Eronen (1998), during 1990–1997 the mean annual rates of pesticides (a.i.) used in sugarbeet fields has been 3.5–5.5 kg/ha. The use of pesticides varied considerably among 400 farms in four different catchment areas in Finland (Seppälä 1999). In one area the mean annual rate, 1.5 kg/ha, was greater than in other areas, 0.4–0.6 kg/ha. In forest nurseries the amounts used were at the same level as those used for some agricultural crops in Finland.

The use of pesticides was asked in two ways: total use during the 1996 growing season and use in growing certain seedling lots. These two ways gave different results. Apparently, it is not possible to calculate the total use of pesticides on the basis of values obtained from detailed information. The timing of permethrin applications explains some of the difference. Two nurseries reported that they sprayed the monitored seedling lot in autumn, and only this use of pesticides was included in the calculations based on detailed information. One explanation could be that nurseries had to use more chemical control in growing of seedling lots other than the monitored one. Another explanation could be that the amounts which nurseries sprayed near the containers (paths and edges) and areas without seedlings were not included in the detailed information.

The use of pesticides varied, not only between nurseries, but also within the same nursery. Some nurseries grew spruce seedlings without chemical control, which meant that there was no pesticide load on the environment from these areas. At many nurseries the largest area was used for growing spruce (Juntunen and Rikala 2001). The highest mean amounts of pesticide were used in production of pine seedlings. In bareroot production, the area for pine was very small; and in container production, the high growing density of pine decreased the area needed.

It should be noted that production of container seedlings is more similar to horticultural production than to agricultural production. Seedlings are started in greenhouses and, depending on seedling type, are raised in greenhouses from two to six months with peat as the growing media. When container seedlings are sprayed with pesticides, most of the pesticide is sprayed on the very densely growing seedlings. In production of container seedlings the pesticides leaching to the ground include both pesticides leaching from the growth medium and pesticides applied directly to aisles and other empty space around the container blocks.

Timing of application may influence leaching. In greenhouses, leaching depends on how well nurseries arrange irrigation (Dumroese et al. 1995). On outdoor areas, leaching depends more on weather conditions, in particular, on the amount of precipitation. Evidently, the application method and skills of the sprayer influence the amount of pesticides sprayed outside containers, i.e. not on seedlings. In most Finnish nurseries, one or two persons are responsible for pesticide application.

For production of bareroot seedlings the situation is similar to that on agricultural fields. On bareroot fields, seedlings grow at much lower density than in containers, and there are empty areas between seedling rows and beds. Much more of the pesticide suspension is applied directly on the ground than in container production. In Finland the soil of bareroot fields is, however, improved with peat, which increases the organic matter content of fields and may prevent leaching of some pesticides.

Places where the risk of herbicide leaching may be high are outdoor areas and edges. These areas are often, at least in Finland, sandy soils with little organic matter. Nor do the sand and stone chips that most nurseries used as material covering outdoor areas prevent possible leaching. Although the nurseries already used textiles to cover the empty spaces between containers, solutions other than chemical control for preventing the growth of weeds on sites without seedlings would be most welcome.

The results presented in this article are based on values given by nurseries concerning their use of pesticides. The coverage of the survey was good, over 80% of the total seedling production in Finland; but the results are based on pesticide use during only one growing season. The pest situation and the need for chemical control at the nurseries vary from year to year depending, for example, on weather conditions (Lilja et al. 1997). In June and July 1996 the weather was favorable for diseases. Both months were rainy and the mean daily temperature was lower than normal. On the other hand, the autumn was warm and dry.

One problem with pesticides is that they are not a homogeneous group, and leaching depends on the characteristics of individual active ingredients. Today, however, forest nurseries in Scandinavia are allowed to use only a very few products. For example, only three herbicides, namely hexazinone (Velpar L®), terbutylazine and glysophate, of the 17 herbicides that nurseries applied during the 1996 growing season, were registered for use in forest nurseries. The nurseries tried, by using other herbicides, to find new solutions for chemical control of weeds, because it was known that terbutylazine (Gardoprim-Neste®) would soon disappear from the market. New products that can be used by nurseries are becoming available less and less often. In reality, there are so few registered products available that nurseries can rarely choose from among several products the one that is least harmful to the environment.

## Acknowledgements

I gratefully acknowledge the personnel of the forest nurseries for answering the questionnaire and thus making this study possible. I thank Dr. H. Heinonen-Tanski, Dr. J. Juzwik, Dr. A. Lilja, Dr. R. Rikala, Dr. H. Smolander and T. Hammar, M.Sc., for valuable comments on the manuscript, and Dr. J. von Weissenberg for revising the English language.

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# III

# Leaching of Nitrogen and Phosphorus During Production of Forest Seedlings in Containers

Marja-Liisa Juntunen*, Taina Hammar and Risto Rikala

## ABSTRACT

Little information is available concerning the contamination risk caused by forest seedling nurseries to local surface and ground waters compared to agricultural and horticultural production. Leaching of nitrogen (N) and phosphorus (P) through peat growing medium in containers and nutrient uptake of seedlings were monitored in actual production of silver birch (*Betula pendula* Roth), Norway spruce (*Picea abies* (L) Karst) and Scots pine (*Pinus sylvestris* L.) seedlings. About half of the applied nutrients (total amount applied: 149 to 260 kg N $ha^{-1}$ and 60 to 108 kg P $ha^{-1}$) was premixed into the peat medium, as is usual in Finnish nursery practice, and the other half was applied to seedlings in liquid form with mobile booms. Depending on tree species 11 to 19% of the applied N was recovered in leachates and 15 to 63% in seedlings. The undiscovered proportion varied from 19 to 71%. The amounts of leached N were 19 to 41 kg $ha^{-1}$. Only 5 to 31% of the applied P was recovered in seedlings; 16 to 64% (11 to 56 kg $ha^{-1}$) was found in leachates. Total N and P load to environment may increase substantially if nutrients applied in liquid fertilization outside container trays are included. Consequently, it is important to determine the sources of nutrient load in container seedling production in order to mitigate the risk of environment contamination.

**Abbreviations:** EC, electrical conductivity, N, nitrogen, P, phosphorus

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## INTRODUCTION

Groundwater pollution and eutrophication of surface waters due to agricultural practices has been reported worldwide. Instead the risk posed by production of forest tree seedlings, even though worldwide, is poorly known (Landis et al., 1991). Although the total use of fertilizers in forest nursery production is small compared to that in agriculture and horticulture, there can be at least local risks because some nurseries are situated on areas where groundwater reservoirs form and/or near lakes and rivers. Seedling production is a part of forest industry, and therefore knowledge of the environmental impacts of nurseries is also needed, for example, in life cycle analyses of wood products (Aldentun 1999).

Mälkki et al. (1988) reported that production of bareroot seedlings may contaminate groundwater with nitrogen (N) compounds from fertilizers. Container seedling production has, however, largely replaced bareroot production in Fennoscandia and Canada. Since the early 1980s the proportion of container production has increased from 30% to over 90% in Finland. Concurrently, annual seedling production has decreased from 250 to 150 million seedlings (Rikala, 2000). These changes have decreased the total amount of fertilizers used in Finnish forest nurseries; in 1976, nurseries used about 650 Mg of fertilizer (Rikala and Westman, 1979) and in 1996 about 200 Mg (Juntunen and Rikala, 2001). On the other hand, the amounts of nutrients applied per unit area in production of container seedlings were higher than in production of bareroot seedlings.

Container seedling production is more intensive than bareroot production due to higher seedling densities and shorter growing times. In 1996, over 90% of all container-grown pine and birch and 43% of spruce seedlings were delivered for planting as one-year-old seedlings, and the rest mostly as two-year-old seedlings in Finland (Juntunen and Rikala, 2001). Growing of container seedlings starts at the end of March in heated greenhouses and later in so-called season greenhouses. The first crops are moved outdoors in early June when the night frosts are over, but many nurseries keep spruce seedling lots in greenhouses until autumn (Juntunen and Rikala, 2001). Over winter most seedlings are stored outdoors under snow cover, which comes between mid-October and mid-December.

During production of container seedlings, a potential risk for nutrient leaching exists, as large volumes of irrigation water are used, and in many countries nearly all fertilizers are applied in liquid form through irrigation systems (=fertigated) (Landis et al., 1989, Dumroese et al., 1995). Among other things, the influence of irrigation volume, application method, fertilizer type on leaching of water and nutrients has been studied with different horticultural crops (Hersey and Paul, 1982, Rathier and Frink, 1989, McAvoy et al., 1992, Fare et al., 1994, Broschat, 1995, Andersen and Hansen, 2000). However, most of the crops studied have been grown in large, individual pots, one to five litres in volume, while forest seedlings are grown in small pots, 40 to 300 ml in volume. The individual pots, in forest nursery terminology often referred to as containers, are usually produced in aggregates called trays (Landis et al., 1990).

Little information is available concerning the total annual amounts of nutrients leached in forest nurseries that use containers. To our knowledge, only Dumroese et al. (1991,1995) have published results on the discharge of water and N during production of container conifer seedlings in a nursery. The aim of this case study was to determine the leaching of N and P through seedling container trays into the ground in actual production.

## MATERIALS AND METHODS

### Study Material and Growing Practices

Leaching of N and P was monitored in container production of silver birch, Scots pine and Norway spruce seedlings at Suonenjoki Nursery in Finland (62°39´N, 27°03´E) in 1995.

Birch seedlings were grown in hard plastic container trays, Plantek, and the spruce and pine seedlings in plastic-laminated paper container trays, Ecopots (Table 1). Containers were filled with medium-grade *Sphagnum* peat (Finnpeat M6, Kekkilä Corp. Finland, http://www.kekkila.fi) premixed with 0.8 kg base fertilizer (N16-P8-K16%) to one cubic meter peat (= 65 kg dry peat). Of the premixed N 44%, 38%, 16% and 3% was in the form of ammonium, ureaformaldehyde, nitrate and urea, respectively. The amounts of N and P applied per unit area or per seedling are given in Tables 2 and 3. The area-based amounts of N and P were calculated by weighing the amounts of peat in the container trays after filling. The dry mass of peat was determined by drying peat samples at 100 °C for 24 hours.

Growing was started in greenhouses (Fig. 1A). Birch seeds were first sown on peat-filled flats on May 2 and the germinants, "small seedlings", were transplanted into containers beginning on May 25. About one month later the birch container trays were transported outdoors and placed 20 cm apart. Conifer seeds, on the other hand, were sown directly into the containers.

Seedlings were irrigated and fertigated with manually controlled mobile-boom sprayers. Both birch and conifer seedlings were irrigated about 20 times a month. At each irrigation session, the birch seedlings were given, on average, 8 mm of

**Table 1.** Dimensions of the container types.

| Tree species | Container tray | Individual container Diameter top/bottom cm | Height cm | Volume $cm^3$ | Number per tray | Number per $m^2$ |
|---|---|---|---|---|---|---|
| Birch | Plantek†, PL25 | 8.0 / 5.2 | 9.0 | 380 | 25 | 156 |
| Spruce | Ecopot†, PS608 | 5.6 / 5.6 | 7.5 | 152 | 104 | 433 |
| Pine | Ecopot, PS508 | 4.6 / 4.6 | 7.5 | 103 | 149 | 620 |
| Pine | Plantek, PL81F | 4.2 / 2.6 | 7.3 | 85 | 81 | 549 |

† Lännen Inc., Finland, http://www.lannenplantsystems.com

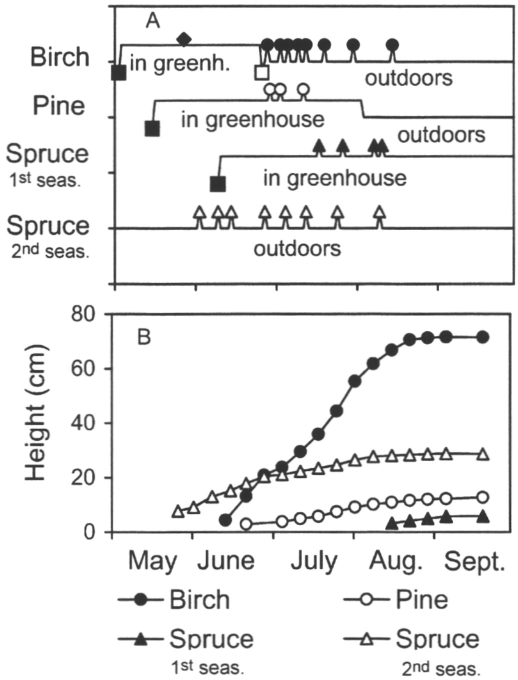


**Figure 1.** Scheduling of culturing practices for birch, pine, first- and second-season spruce (A) and height development of seedlings during the 1995 growing period (B). ■ = sowing, ♦ = transplanting, ❑ = separation of trays, symbols for tree species in Figure B describe the dates of liquid fertilization in Figure A.

water (50 ml per seedling) and conifer seedlings 5 mm of water (about 10 ml per seedling). Due to rain, the second-season spruce seedlings, which were grown outdoors during the whole season, were irrigated only about six times a month. At each irrigation, 8 mm of water (about 20 ml per seedling), on average, was applied. The water content of the growing medium was monitored weekly by weighing container trays; the aim was to maintain the water content of the peat medium at optimum level (= 40–55% v/v, Puustjärvi, 1977).

The timing of fertigations was determined by measuring the electrical conductivity (EC) of the press water from peat medium weekly as in the normal nursery routine (Juntunen and Rikala, 2001). The seedlings were fertigated 3 to 8 times (Fig. 1A) with Superex fertilizers (Kekkilä Corp.), in which about 50% of the N was applied as urea, 37% as nitrate and over 10% as ammonium.

In 1996, the leaching studies were replicated in the production of one-year-old pine seedlings grown in Ecopot and Plantek container trays (Table 1). The seedlings were grown in the same manner as pine seedlings in 1995 (Fig. 1A), except that the plastic cover was removed one week earlier. Due to the greater filling density of peat in Plantek than in Ecopot container trays, the amounts of premixed N and P per seedling were the same even though the volume of Plantek containers was smaller (Table 1). Obviously, the tapering form of the Plantek containers was the reason for the greater filling density. Both container types were fertigated three times with the same amount of Superex fertilizer per unit area (Tables 3 and 4).

## Collection and Analyses of Leachate Samples

For collecting leachate waters, sloped polystyrene plates (size of container trays, either 40 cm x 40 cm for Plantek or 60 cm x 40 cm for Ecopot) equipped with a hole and a sampling vessel were placed under the container trays (Table 2). The plates were exactly the size of the container trays and therefore only the leachate was collected; neither irrigation water nor rainfall could hit the plates. Collection of leachates began from the time the conifers were sowed and the birch germinants transplanted and continued until the peat growing medium froze in late October.

The volume, EC (CDM80, Radiometer, Denmark) and pH (3020, Jenway, England) of leachates were measured daily (excluding Saturday and Sunday) during 1995 and weekly in 1996. Samples were stored frozen 3–4 months before nutrient analyses. When amounts of leachate were small and EC values were at the same level, samples from two to four successive sampling times were pooled before nutrient analyses.

Total N in the leachate samples was measured according to the standard SFS-EN ISO 11905-1 and $PO_4$-P according to SFS 3025. The sum of $NO_3$-N and $NO_2$-N was determined by the FIA (flow injection analysis) method (Lachat Quick Chem 8000) according to the standard SFS-EN ISO 13395. $NH_4$-N was analysed spectrophoto-

**Table 2.** Number of replicate trays for leachate analyses of nitrogen compounds (N) and phosphorus (P) and number of sample seedlings per tray for height monitoring and morphological measurements.

| Year and tree species | Container type | Leachate analyses N | Leachate analyses P | Height monitoring | Morphological measurements |
|---|---|---|---|---|---|
| 1995 | | | | | |
| Birch | Plantek | 6 | 2 | 5 | 5 |
| Spruce | Ecopot | 5 | 1 | 10 | 20 / 10† |
| Pine | Ecopot | 5 | 1 | 10 | 15 |
| 1996 | | | | | |
| Pine | Ecopot | 3 | 1 | 10 | 15 |
| Pine | Plantek | 3 | 1 | 10 | 15 |

† first-season spruce / second-season spruce

metrically (SFS 3032) and the fraction of organic N was determined by subtracting inorganic N from total N.

### Seedling Measurements

During the growing season, the height growth of seedlings was measured weekly (Fig. 1B, Table 2). When leachate collection was stopped, seedlings were harvested (Table 2); and leaves, stems with branches (later referred to as stems) and roots were separated and dried (roots after washing) for 48 hours at 60°C before they were weighed. For nutrient analysis, the leaves, stems and roots were pooled separately by trays. N concentration was determined with a LECO CHN-600 analyzer (Leco Co, St Joseph USA), and P concentration was determined from dry-digested (2 M HCL) samples (Halonen et al., 1983) using plasma emission spectrophotometric analysis (ICP, ARL 3800).

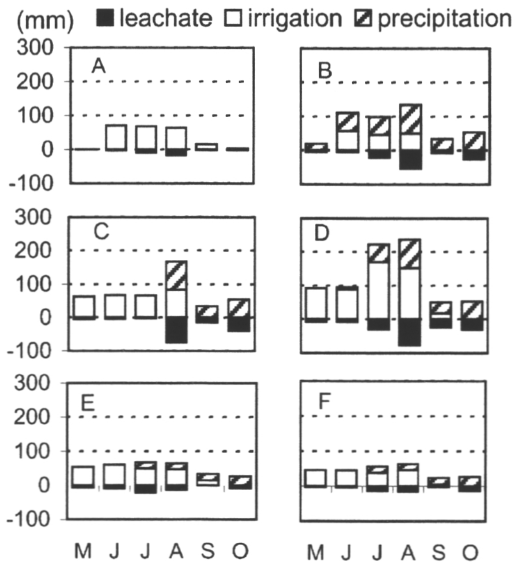


**Figure 2.** Monthly amounts of precipitation, irrigation and leachate (mm) for first-season spruce (A), second-season spruce (B), pine (C) and birch (D) in 1995, and for pine in Ecopot (E) and Plantek (F) containers in 1996.

## RESULTS

### Monitoring 1995

On average (s.d. in parenthesis), 25 (3), 122 (23), 141 (10) and 175 (30) mm of water leached through first-season spruce, second-season spruce, pine and birch container trays, respectively (Fig. 2A–D). Depending on tree species, 11 to 31% of the applied water (irrigation + precipitation) leached through the trays. During the greenhouse period, leaching was less than 10%. In the autumn, 50 to 70% of rainwater leached through the trays, because during rainy periods with decreased evapotranspiration the water content of peat medium exceeded the container capacity (data not shown). From all tree species over 50% of the total leachate water

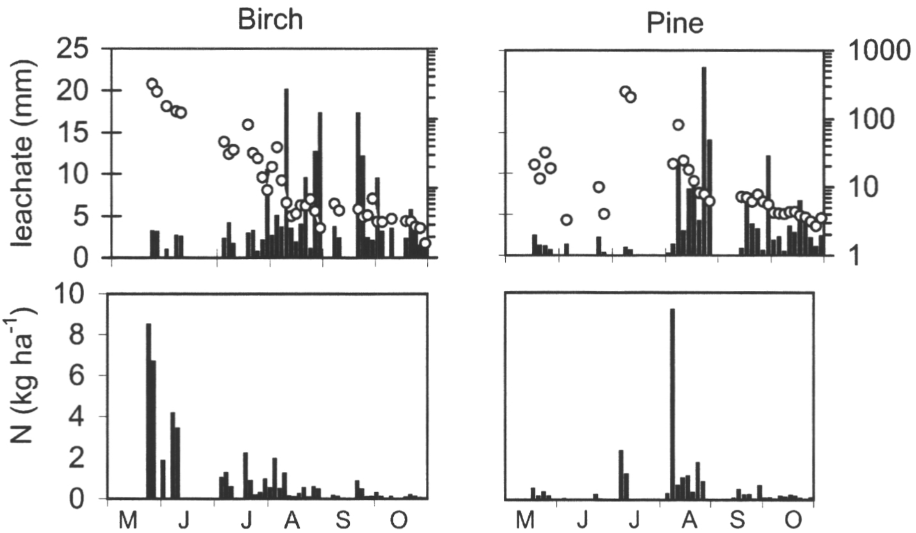


**Figure 3.** Leachate volume (mm, bars), N concentration (mg $L^{-1}$, dots) and amount (kg $ha^{-1}$, bars) of N leached from birch and pine containers from May to October in 1995.

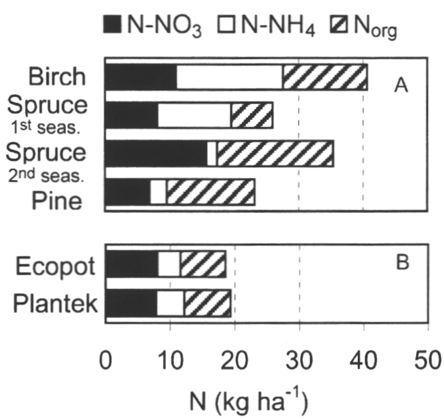


**Figure 4.** Leached amounts of $NO_3$-N, $NH_4$-N and organic N by tree species in 1995 (A) and by container types in 1996 (B).

was collected during July and August after the container trays were moved outdoors.

The amounts of leached N per unit area varied from 23 to 41 kg $ha^{-1}$, depending on tree species (Table 3). The same proportion (13 to 19%) of applied N was recovered in all leachates regardless of species. In birch seedling production, almost 50% of the total N recovered in the leachates occurred during May and in early June. About 50 to 90% of the N leachate from conifer trays was measured during July and August (= fertigation period) (Fig. 3). After the beginning of September less than 15% of the total N leached through trays of any tree species.

The highest concentrations of N, ca 300 mg $L^{-1}$, were measured in the leachates from birch trays just after the germinants were transplanted but then decreased to less than 10 mg $L^{-1}$ at the end of August (Fig. 3). In leachates from conifer trays, N concentrations were usually 20 to 50 mg $L^{-1}$, while some occasional peaks of 100 to 200 mg $L^{-1}$ were measured (Fig. 3). In September and October the N concentrations were less than 10 mg $L^{-1}$.

Depending on tree species, 24 to 54% of the N leached as $NO_3$-N, 7 to 46% as $NH_4$-N and 24 to 59% as organic N (Fig. 4). The largest amounts of $NO_3$-N (16 kg $ha^{-1}$) were found in the leachates of second-season spruce. From birch and first-season spruce containers N leached mainly as ammonium. Small amounts of organic N were measured in leachates throughout the growing season; but after the end of August, in all water samples almost all the leached N was in organic form.

The amount of leached P and its proportion of the applied P differed greatly among tree species (Table 4). In leachates of birch and pine over 50% of the applied P was recovered, but

**Table 3.** Amounts of N applied and recovered in leachate and in seedlings by tree species in 1995 and in 1996. The values are given both per unit area and per seedling.

| Year and tree species | N applied kg ha$^{-1}$ (mg per seedling) | | | N recovered kg ha$^{-1}$ (mean ± s.d.) (mg per seedling) | | | Proportion of applied (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | premixed to peat | in fertigat. | total applied | in leach. | in seedl. | not discov. | in leach. | in seedl. | not discov. |
| 1995 | | | | | | | | | |
| Birch | 85 | 175 | 260 | 41±13 | 164±19 | 55±16 | 16 | 63 | 21 |
| | (55) | (112) | (167) | (26±8) | (105±12) | (36±10) | | | |
| Spruce | 97 | 93 | 190 | 26±2 | 29±3 | 135±4 | 14 | 15 | 71 |
| 1st seas. | (22) | (22) | (44) | (6±1) | (7±1) | 31±1) | | | |
| Spruce | | 185 | 185 | 35±9 | 115±14 | 35±15 | 19 | 62 | 19 |
| 2nd seas. | | (43) | (43) | (8±2) | 27±3)† | (8±3) | | | |
| Pine | 96 | 87 | 183 | 23±4 | 95±5 | 65±8 | 13 | 52 | 35 |
| Ecopot | (16) | (14) | (30) | (4±1) | (15±1) | (11±1) | | | |
| 1996 | | | | | | | | | |
| Pine | 96 | 68 | 164 | 19±4 | 68±12 | 77±15 | 11 | 42 | 47 |
| Ecopot | (15) | (11) | (26) | (3±1) | (11±2) | (12±2) | | | |
| Pine | 81 | 68 | 149 | 19±2 | 42±7 | 88±8 | 13 | 28 | 59 |
| Plantek | (15) | (12) | (27) | (3±0.4) | (8±1) | (16±2) | | | |

† Total N content minus amount taken by seedlings during the first season, 7 mg N per seedling (29 kg ha$^{-1}$)

in leachates of spruces only 25% or less. About 80% of the P premixed into peat leached through birch containers in May and in early June.

$PO_4$-P concentrations in the leachates from birch containers followed the pattern for N concentrations; they were at highest, 200 to 300 mg L$^{-1}$, just after the germinants were transplanted and decreased gradually during the summer (not shown). The concentrations of $PO_4$-P in the leachates from conifer trays varied greatly, from 5 to 100 mg L$^{-1}$, and there was no clear trend over time. After August, however, the concentrations were always less than 10 mg L$^{-1}$.

About the same proportions, 52 to 63% of the applied N and 25 to 31% of applied P, were recovered in seedlings (Tables 3 and 4). The first-season spruce seedlings were an exception; they took up only 15% of the applied N and 5% of the applied P.

## Monitoring 1996

On average (s.d. in parenthesis), 53 (9) and 47 (14) mm of water leached through Ecopot and Plantek pine trays (Fig. 2E–F). Over half of the leachate was collected in July and August after container trays have been moved outdoors. Due to a dry autumn, the amounts of water leached in September were very small. The amounts of N leached through the two container types were the same (19 kg ha$^{-1}$) (Fig. 4B). Nearly all the N leached in late July and August. A greater amount of P leached through the Plantek than through Ecopot tray (Table 4). Seedlings grown in Ecopot container trays took up more N and P than those grown in Plantek containers (Tables 3 and 4).

## DISCUSSION

The annual amounts of leached N and P, 19 to 41 and 11 to 56 kg ha$^{-1}$, respectively, were small compared to those measured in studies of horticultural crops (van der Boon and Niers, 1983, Broschat, 1995). Comparison with horticultural studies was, however, difficult because the amounts of nutrients leached have often been given per pot instead of per unit area, and the fertilizer system and methods used were different from those used in forest nurseries. Based on the results by Dumroese et al. (1995), we calculated that in production of ponderosa pine (*Pinus ponderosa*) the total N discharge was about 130 N kg ha$^{-1}$.

Obviously, the irrigation method used in this

**Table 4.** Amounts of P applied and recovered in leachate and in seedlings by tree species in 1995 and in 1996. The values are given both per unit area and per seedling.

| Year and tree species | N applied kg ha$^{-1}$ (mg per seedling) premixed to peat | in fertigat. | total applied | N recovered kg ha$^{-1}$ (mean ± s.d.) (mg per seedling) in leach.† | in seedl. | not discov. | Proportion of applied (%) in leach. | in seedl. | not discov. |
|---|---|---|---|---|---|---|---|---|---|
| 1995 | | | | | | | | | |
| Birch | 44 | 64 | 108 | 56 | 27±3 | 25 | 52 | 25 | 23 |
| | (28) | (41) | (69) | (36) | (17.2±1.9) | (16) | | | |
| Spruce | 49 | 29 | 78 | 20 | 4 ± 1 | 54 | 25 | 5 | 70 |
| 1st seas. | (11) | (7) | (18) | (4) | (0.9±0.04) | (13) | | | |
| Spruce | | 84 | 84 | 15 | 26±3 | 43 | 17 | 31 | 52 |
| 2nd seas. | | (19) | (19) | (3) | (6.1±0.7)‡ | (10) | | | |
| Pine | 48 | 24 | 72 | 46 | 20±2 | 6 | 64 | 28 | 8 |
| Ecopot | (8) | (4) | (12) | (8) | (3.3±0.3) | (1) | | | |
| 1996 | | | | | | | | | |
| Pine | 48 | 19 | 67 | 11 | 14±2 | 42 | 16 | 22 | 62 |
| Ecopot | (8) | (3) | (11) | (2) | (2.3±0.3) | (7) | | | |
| Pine | 41 | 19 | 60 | 21 | 9±1 | 30 | 35 | 15 | 50 |
| Plantek | (8) | (3) | (11) | (4) | (1.6±0.3) | (6) | | | |

† Analysed only from one replicate as $PO_4$-P
‡ Total P content minus amount taken by seedlings during the first season, 1 mg P per seedling (4 kg ha$^{-1}$)

nursery study explains the small amounts of leachate and partly explains the small amounts of N and P leached. An attempt was to made to keep the water content of the peat medium at optimum level, 40–55% v/v (Puustjärvi, 1977), by monitoring container weight weekly, as is the practice in most Finnish nurseries (Juntunen and Rikala, 2001). Therefore the amounts of leachate (25–175 mm) were small, especially during the greenhouse period. In the study of Dumroese et al. (1995) the amounts of discharged water were as large as 450 to 800 mm. Finnish forest nurseries do not irrigate and fertigate in excess of container capacity as some forest and ornamental nurseries do (McAvoy et al., 1992, Yelanich and Biernbaum, 1993, Dumroese et al., 1995) in order to reduce the potential for accumulation of soluble salts and nutrient imbalance (Landis et al., 1989, Biernbaum, 1992). The greater the leachate fraction, the greater is the risk of nutrient contamination of the environment (McAvoy et al. 1992).

The amounts of nutrients applied by Suonenjoki nursery were virtually the same as the mean total amounts of nutrients applied by Finnish nurseries in 1996 (Juntunen and Rikala 2001). The frequency of fertigations was, however, lower than the average (once a week) for Finnish nurseries. The few fertigations must have caused high peaks in the nutrient content of the peat medium. When the nutrient content of peat is large, irrigation water and rain could leach nutrients. In 1995, for example, a heavy rainfall (10 mm) that occurred soon after one fertigation leached about one-third of the total N leached from the pine and second-season spruce container trays during the whole collection period. The experiences of van der Boor and Niers (1983) in an ornamental nursery were similar. In growing of first-season spruce, almost all leaching of N and P occurred in connection with fertigations. Due to the few fertigation sessions, the fertilizer doses and the amounts of water applied were large, which increased leaching.

The other situation, where the nutrient content of peat was large, was at the beginning of seedling growth because of the fertilizer premixed into peat medium. In production of birch seedlings, large amounts of N and P leached with small amounts of water in May and in early June. The large volume of the birch containers might have increased the leaching of nutrients, because during the first growing month birch and pine did not differ either in fertilization or in amounts of leachate water.

In many studies only the leaching of $NO_3$-N has been measured (Rathier and Frink, 1989, Fare et al., 1994, Broschat, 1995, Andersen and Hansen, 2000), obviously because the $NO_3$-N levels 10 mg $L^{-1}$ (USEPA, 1983) or $NO_3$-levels 50 mg $L^{-1}$ ($NO_3$-N 11.3 mg $L^{-1}$) (European Community, 1998) in drinking water are considered unsafe for humans. In our study, however, the amounts of $NO_3$-N in leachates covered only 25 to 54% of the total N leached. Ammonium and organic N compounds can also increase the risk of groundwater contamination, since they can later be transformed to nitrate in the soil (Addiscott et al., 1991, Colangelo and Brand, 2001). Therefore, apparently $NO_3$-N analyses are not enough; when the risk of contamination is evaluated, at least total N analyses are also needed.

The proportion of N that leached through the peat medium, was fairly constant at 11 to 19% of applied N, while the proportions of P (16 to 64%) recovered in leachates varied greatly. The large amounts of P in leachates do, however, indicate that P leaches easily from peat medium. Based on measurements of P adsorption isotherms, Marconi and Nelson (1984) came to the same conclusion.

The proportion of N and P not recovered in leachates and seedlings was generally high, over 50%, which means that nutrient losses into the nursery environment due to leaching cannot be monitored with precision using only the nutrient content of seedlings. With the nutrient content of the crop, only the magnitude of the risk of leaching can be estimated. Because the growing medium was not analyzed, it is not possible to know whether the nutrients remained in the peat medium in late October or whether N had volatilized into the atmosphere during the summer and autumn. However, we speculate that very little soluble P and inorganic N were in the peat medium after the end of August because the amounts of these elements in the leachates were small.

In the production of container seedlings, the total nutrient load consists of the amounts of nutrients leached from containers into the ground and fertigated directly into the ground outside the seedling trays. Based on the dimensions of the greenhouses and the coverage of seedling trays, we estimated that about 10–20% of the water volume was irrigated alongside the conifer containers. It can be concluded that in pine production fertigation outside seedlings, 17 kg N $ha^{-1}$ (= 20% x 87 kg N $ha^{-1}$), and leaching through seedling trays, 18 kg N $ha^{-1}$ (= 80% x 23 kg N $ha^{-1}$), caused an equal N load. In birch production about half of the fertigation water fell outside container trays because of the separation of birch trays. In this situation the load caused by fertigations directly on the ground was much greater, 88 kg N $ha^{-1}$ (= 50% x 175 kg N $ha^{-1}$), than the load of N leached, 20 kg N $ha^{-1}$ (= 50% x 41 kg N $ha^{-1}$).

The annual leaching of N through container medium into the ground was the same order of magnitude as the mean losses of N, about 18 to 20 kg ha $^{-1}$, from Finnish agricultural fields (Rekolainen et al., 1993). The P leached in substantially greater amounts than what had been measured from agricultural fields, 0.95 to 1.7 kg ha $^{-1}$ (Rekolainen et al., 1997). The amounts of N and P fertigated outside the container trays, however, increased the total load of N and P per unit area. In addition, the same type of production continuing at the same places for years and most of annual nutrient leaching occurring during one or two months could increase the risk of contamination. It is difficult to say when the amounts of nutrients discharged are so great that there could be a risk of harmful environment contamination. Many factors related to a nursery, such as depth of the water table, characteristics of soil layers between the ground and ground water reservoirs and nearness of rivers and lakes, influence the risk of contamination.

Changes in fertilization methods, for example, increasing the frequency of applications and/or applying the nutrients in exponentially increasing additions instead of at constant rate of addition (Timmer, 1997), could increase the nutrient-use efficiency of seedlings and decrease the amount of nutrients applied and discharged. By premixing slow-release fertilizers, also known as controlled-release fertilizers (Landis et al., 1989), into growing medium it may be possible to avoid fertigations and decrease the amounts of nutrients applied directly on the ground. The elimination of rain by covering outdoor areas with movable roofs could also be worth studying. Making changes in nursery practices in order to decrease the environmental impacts of forest nurseries may increase production costs. At the same time, however, it can be assumed that many of these measures will improve seedling quality.


## Acknowledgements

We thank the staff of Suonenjoki Nursery and Research Station for good co-operation during the experiment and the laboratory personal of North Savo Regional Environment Centre for making the chemical analyses. Special thanks to Sirpa Metsärinne, M.Sc., and Mikko Maukonen, M.Sc., for technical assistance. We also thank Dr. H. Heinonen-Tanski, Dr. H. Smolander, R. Richardson, M.Sc.(For) and anonymous referees for valuable comments on the manuscript, and Dr. J. von Weissenberg for revising the English language. We gratefully acknowledge financial support from Pohjois-Savon Liitto and Metsäosaamiskeskus-hanke.


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# IV

# Nitrogen and Phosphorus Leaching and Uptake by Container Birch Seedlings (*Betula pendula* Roth) Grown in Three Different Fertilizations

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**Accepted**

**Key words:** agricultural pollution, controlled-release fertilizer, groundwater, nursery, nutrient uptake, slow-release fertilizer

**Abstract.** Leaching of nitrogen (N) and phosphorus (P) through container peat medium and N and P uptake by seedlings were determined in commercial production of birch grown with three different types of fertilization. Half of the amount of nutrients was premixed into the peat medium and the other half was applied as liquid (=fertigated) in the treatment (PF) commonly used in Finland. In two other treatments all nutrients, either totally (P-VN) or partly (P-N) in slow-release form, were premixed into the peat. Independently of the treatment, the largest proportion (60 to 80%) of total N leached during May and June. During two growing seasons, the amounts of N leached from PF treatments (9 to 36 kg $ha^{-1}$) were as large as the amounts of N leached from P-VN and P-N treatments (24 to 46 kg $ha^{-1}$). Due to fertigations between container trays, however, the total N load per hectare was greatest in the PF treatments. In the soil water 0.5 meter beneath the container area, the N concentration varied from 10 to 60 mg $l^{-1}$. The morphological and chemical properties of the seedlings did not differ greatly between treatments.

# Introduction

Nutrients derived from fertilizers cause eutrophication of surface waters and contamination of groundwater. Nitrate, in particular, is a hazard for groundwater (Brown 1991). $NO_3$ –levels greater than 50 mg $l^{-1}$ ($NO_3$-N 11.3 mg $l^{-1}$) in drinking water are considered unsafe for humans (European Community 1998). In the production of forest container seedlings there is a risk of nutrient leaching, as large volumes of irrigation water are used and nearly all fertilizers are applied through irrigation systems (Dumroese et al. 1995, Juntunen and Rikala 2001). In a Finnish container nursery, the amounts of nitrogen (N) and phosphorus (P) leached from containers into the ground were, depending on tree species, 23 to 41 kg $ha^{-1}a^{-1}$ and 15 to 56 kg $ha^{-1}a^{-1}$, respectively (Juntunen et al. 2002).

Irrigation frequency and method (Conover and Poole 1992, Lamack and Niemiera 1993, Fare et al. 1994, Morvant et al. 1998), amounts of nutrients applied and fertilization method (Rathier and Frink 1989, Yelanich and Bierbaum 1993, Broschat 1995) affect percolation of water and leaching of nutrients. It is possible to increase the efficiency of nutrient use by seedlings and decrease the total amount of applied nutrients (Timmer and Amstrong 1987) by applying nutrients according to growth demands (Ingestad and Lund 1986).

By premixing slow-release fertilizers, also known as controlled-release fertilizers (Trenkel 1997), into growing medium it may be possible to avoid fertigation and decrease the amounts of nutrients applied directly on the ground. There are two basic types of slow-release nitrogen fertilizers: coated fertilizers and fertilizers with sparingly soluble nitrogen compounds (Oertli 1980, Landis et al. 1989, Shaviv and Mikkelsen 1993, McNabb and Heser 1997). Environmental factors, e.g. temperature, moisture, pH and aeration, affect the release of nutrients from both types of fertilizers.

The use of slow-release fertilizers could decrease the total nutrient load, especially if pots or container trays do not completely cover the fertigation area. In Finnish nurseries, about one month after sowing, birch container trays are separated from each other by 20 cm of free space (Juntunen and Rikala 2001). The separation increases the flow of air between seedlings, preventing fungal diseases and improving the morphology of the seedlings. It also doubles the growing area, which means that about half of the irrigation water and fertigated nutrients are applied between containers.

In the production of container birch seedlings, we investigated three fertilizer treatments with nutrients in soluble and slow-release form. The objective was to determine the leaching of N and $PO_4$-P through peat container medium into the ground and the effects of these treatments on nutrient uptake by seedlings. The N and $PO_4$-P concentrations in soil water beneath the container area were also measured.

# Materials and methods

The field study was conducted as part of the commercial production of silver birch (*Betula pendula* Roth) container seedlings at Suonenjoki Research Nursery (62°39´N, 27°03´E) in 1997 and 1998. The birch seeds (seed orchard 379, M29-92-0001) were sown at the beginning of May on peat-filled flats. Three weeks later the germinants were transplanted to peat-filled hard plastic containers (Plantek25; V=380 $cm^3$, 25 pots/tray =156 pots/$m^2$ Lännen Inc., Finland). Commercial sphagnum peat, "Kasper" forest seedling peat produced by Garden Peat Corp., Finland, and "D1K1" forest seedling peat produced by Vapo Corp., Finland, was used as growing medium in 1997 and 1998,

**Table 1.** Nutrient concentrations (g $kg^{-1}$ or mg $kg^{-1}$ fertilizers) of the fertilizers used in treatments.

| | GP | ST | Vital Nursery | Nutricote T70 |
|---|---|---|---|---|
| | | Nutrients g $kg^{-1}$ fertilizer | | |
| N | 150 | 160 | 90 | 160 |
| P | 70 | 80 | 40 / 35[2] | 44 |
| K | 150 | 160 | 50 | 83 |
| S | 23 | 30 | 38 | |
| Mg | 55[1] | 55[1] | 48 | |
| Ca | 200[1] | 200[1] | 132 / 93 [2,3] | |
| | | Nutrients mg $kg^{-1}$ fertilizer | | |
| Fe | 400 | 800 | 500 | |
| Mn | 300 | 300 | 800 | |
| Cu | 200 | 200 | 500 | |
| Zn | 100 | 100 | 400 | |
| B | 50 | 50 | 400 | |
| Mo | 30 | 30 | 150 | |

[1] in kg magnesium-rich lime; [2] 1997 / 1998; [3] mainly from biotite and apatite

respectively. The seedlings were grown in a greenhouse until the plastic cover was removed on June 25 in 1997 and on June 24 in 1998. At the same time the container trays were separated from each other and placed 20 cm apart. The experiment ended on October 14 in 1997 and on October 13 in 1998, when the seedlings were moved into frozen storage.

In the first treatment, later referred to as PF treatment (premixed fertilizer + fertigation), the peat producer added either GP fertilizer (1997) or ST fertilizer (1998) and magnesium-rich lime into the peat (Table 1). Part of the N compounds in both fertilizers was soluble and part was in slow-release form, as methylene urea. The premixed fertilizer included more than half of the total amount of nutrients applied to the seedlings (Table 2). The rest of the applied nutrients were given to the seedlings at four fertigation times (July 3, 10, 21 and August 1 in 1997 and July 7, 21, 31 and August 12 in 1998).

In the second treatment, later referred to as P-VN treatment ("Vital Nursery"), four kilograms of the fertilizer "Vital Nursery" ("Taimiston Kestolannos" Kemira Corp., Finland) (Table 1), as recommended by the manufacturer, were premixed by the peat producer into one cubic meter peat in 1997 and 1998. The source of N in the fertilizer was methylene urea. According to the manufacturer, mineralization of the methylene urea fractions soluble in cold water, soluble in hot water and insoluble in water takes

**Table 2.** Amounts of N and P (kg $ha^{-1}$) applied in premixed fertilizer and in fertigation in different treatments and years. Treatments: PF = GP (1997) and ST (1998) fertilizer premixed into peat + fertigation, P-VN = fertilizer "Vital Nursery" premixed into peat, P-N = ST fertilizer + NutricoteT70 premixed into peat. The number 97 after the treatment means the year 1997 and 98 indicates the year 1998.

| N and P form | PF97 | P-VN97 | Treatment<br>PF98 | P-VN98 | P-N98 |
|---|---|---|---|---|---|
| | | | N and P kg $ha^{-1}$ in premixed fertilizer | | |
| Nitrate | 40 | – | 17 | – | 17 |
| Ammonium | 11 | – | 47 | – | 49 |
| Urea | 3 | 13 | 3 | 17 | 3 |
| Methylene urea, | | | | | |
| Soluble in cold water | 17 | 75 | 13 | 94 | 14 |
| Soluble in hot water | 26 | 118 | 17 | 147 | 18 |
| Insoluble in water | 14 | 62 | 11 | 77 | 11 |
| Nitrate in prills | – | – | – | – | 139 |
| Ammonium in prills | – | – | – | – | 139 |
| P water-soluble | 40 | 26 | 41 | 30 | 42 |
| P insoluble in water | 11 | | 14 | | 14 |
| P from apatite | | 93 | | 100 | |
| P from prills | | | | | 76 |
| N Total | 111 | 268 | 108 | 335 | 390 |
| P total | 51 | 119 | 55 | 130 | 132 |
| | | | N and P kg $ha^{-1}$ in fertigation | | |
| Nitrate | 32 | – | 23 | – | – |
| Ammonium | 8 | – | 6 | – | – |
| Urea | 21 | – | 20 | – | – |
| N total | 61 | – | 49 | – | – |
| P total | 19 | – | 23 | – | – |

**Table 3.** Irrigation, precipitation (mm), mean daily temperature (°C) and temperature sum (d.d., with threshold temperature of +5 °C) from the transplanting of germinants by treatments, years and months. For treatments, see legend in Table 2.

| Month | Treatment PF, P-VN 1997 | PF 1998 | P-N, P-VN 1998 | 1997 | 1998 | 1997 | 1998 | 1997 | 1998 |
|---|---|---|---|---|---|---|---|---|---|
| | Irrigation, mm | | | Precipitation, mm | | Mean temp., °C | | Temp. sum, d.d. | |
| May | 49 | 35 | 42 | + | + | 14 | 10 | 132 | 124 |
| June | 95 | 45 | 27 | 18 | 0 | 19 | 17 | 585 | 519 |
| July | 181 | 67 | 72 | 113 | 147 | 19 | 16 | 1160 | 1020 |
| August | 126 | 21 | 34 | 19 | 100 | 17 | 13 | 1686 | 1420 |
| September | 0 | 27 | 28 | 59 | 21 | 9 | 10 | 1966 | 1719 |
| October | 0 | 5 | 6 | 26 | 22 | 3 | 3 | | |
| Total | 451 | 200 | 209 | 235 | 290 | | | | |

+ seedlings in greenhouse

weeks, months and more than a year, respectively (Table 2). Part of the P, K and Mg was also in slow-release form; the source of these forms was apatite for P and biotite for K and Mg. The fertilizer also included micronutrients (Table 1). According to the manufacturer, no liming was needed because of the liming effect of biotite and apatite. In 1998 the filling density of containers was higher than in 1997. On average, there were 189 grams more dry peat in one container tray in 1998 than in 1997, and therefore the amount of nutrients was also greater (Table 2).

In the third treatment, studied only in 1998 and later referred to as P-N treatment (ST fertilizer + Nutricote), two kilograms of Nutricote T70 fertilizer (Nichimen Corp., Japan) (Table 1), in addition to the amount of ST fertilizer and magnesium-rich lime used in the PF treatment, were premixed by the peat producer into one cubic meter of peat (Table 2). According to the manufacturer, at 20 °C all N, P and K from the Nutricote fertilizer prills should be released in 70 days; but at 15 °C the release time could be more than 100 days.

The seedlings were irrigated and fertigated (PF treatments) with manually controlled mobile boom sprayers. The timing of irrigation and fertigation was determined according to normal nursery routine by weighing container trays and measuring the electrical conductivity of the press water from the peat medium weekly. The aim was to maintain the water content of the peat medium at optimum level (= 40 to 55% v/v, Puustjärvi 1977). The amounts of irrigation and precipitation were recorded daily (see Table 3). All experiments were carried out in two adjacent greenhouses. The mean daily temperatures were higher in summer 1997 than in summer 1998, which caused the temperature sum (with base temperature of +5 °C) to be greater during the 1997 growing period than during the 1998 growing period (Table 3).

For collecting the leachate water, four trays per fertilizer treatment were placed systematically among the commercial production stock in the greenhouses. The leachate samples were collected in sloped polystyrene plates (40x40 cm) placed under each container tray and equipped with a hole and a sampling vessel. The leachates were collected once a week.

The volume of leachates, electrical conductivity (EC)(CDM80, Radiometer, Denmark) and pH (3020, Jenway, England) were determined. The samples were stored frozen for 3 to 4 months before analyzed for nutrient concentration. If the amounts of leachate were small and the EC values were at the same level, samples from 2 to 3 successive sampling times were pooled before the nutrient analyses. Total N and $PO_4$-P were measured according to Finnish standard methods (SFS-EN ISO 11905-1, 1998 and SFS 3025, 1986). The sum of $NO_3$-N and $NO_2$-N was determined by the FIA (flow injection analysis) method (Lachat Quick Chem 8000, Lachat Insturments, USA) according to the standard SFS-EN ISO 13395 (1997). $NH_4$-N was analysed spectrophotometrically (SFS 3032, 1976), and the organic N fraction was determined by subtracting inorganic N from total N.

Soil water was collected using tension lysimeters (P80 ceramic cups, Ceramtec AG) from three points at a depth of 0.5 m beneath a greenhouse from May to the beginning of November. In 1997, soil water was collected from two points (six meters between points, four cups per point in a square, 0.5 meter between cups) beneath the P-VN treatment and from one point (eight cups in a rectangle, 0.5 meter between cups) beneath the PF treatment. In 1998 all cups were beneath the P-VN treatment. The suction was continuous and the pressure in the cups varied from –20 to –60 kPa. The water from each cup was collected into a glass bottle; these bottles were kept in covered boxes. The water from the bottles was collected every two weeks. The volume, EC and pH of each sample were measured as described above. Then the water samples from one collecting point were pooled and stored frozen for chemical analysis.

At the end of August the leaves of 20 seedlings per treatment (5 seedlings per tray) were sampled, and the leaf area (Li-Cor, model LI-3000, USA) and dry mass of the leaves on each seedling were determined. In the middle of October, 20 seedlings per treatment (5 seedlings per tray) were harvested, and their heights and diameters (2 cm above the peat surface of root plug) were measured. Stems with branches (later stems) and roots were separated; the roots were washed and dried for 48 hours at 60°C before they were weighed. For nutrient analysis, stems and roots were pooled separately for each tray. Fallen leaves were collected on experimental trays (four samples per treatment, one sample per tray) and analyzed after they were dried. N concentration was determined with a LECO CHN-600 analyzer (Leco Co, St Joseph USA), and P concentration was determined from dry-digested (2 M HCL) samples (Halonen et al. 1983) using plasma emission spectrophotometric analysis (ICP, ARL 3800).

Data were analyzed with a t-test (1997) and one-way ANOVA combined with Tukey's Multiple Range Test (1998) using the SPSS Win7.0 program. The four sample trays per treatment were used as replicates in analysis, although for practical reasons these trays were placed systemically among commercial production and they were not true independent replicates. Because the peat used in 1997 and 1998 was from different producers, the influence of years was not tested for statistical significance.

# Results

### Percolation of water

A total of 20 to 30% of the irrigation and precipitation water percolated through the containers (Figure 1). Less than 10% of irrigation water percolated during the greenhouse period, in July and August the percolation was about 20% of the input, but in September and October the proportion of percolation from precipitation varied from 50 to 94%. The total percolation of water through containers of PF treatment was 57 mm less ($p<0.01$) than that of P-VN treatment in 1997, even though the irrigation of containers was the

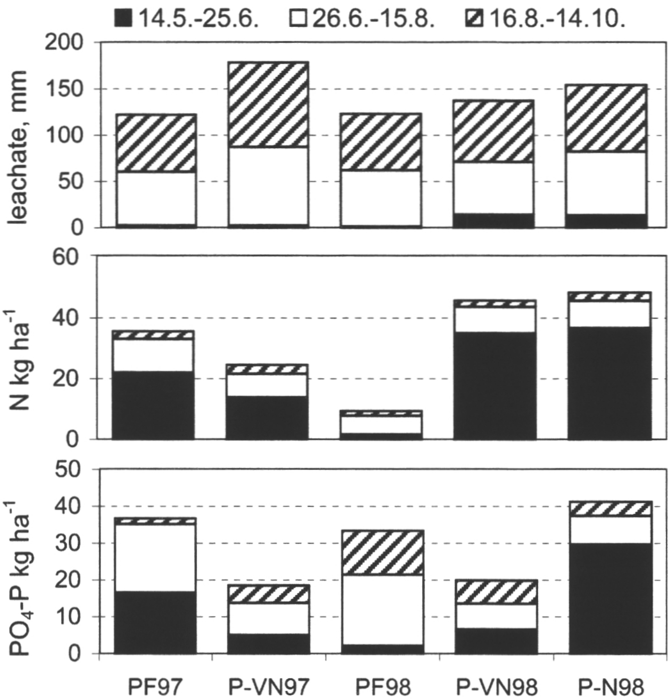


**Figure 1.** Amount of leachate (mm) and N and $PO_4$-P (kg $ha^{-1}$) in leachates originating from three fertilizer treatments. PF = GP (1997) and ST (1998) fertilizer premixed into peat + fertigation, P-VN = fertilizer "Vital Nursery" premixed into peat, P-N = ST fertilizer + NutricoteT70 fertilizer premixed into peat. The number 97 after the treatment means the year 1997 and 98 indicates the year 1998. The amounts of leachates and N and $PO_4$-P are presented for three periods: 14.5.–25.6., 26.6.–15.8., 16.8.–14.10.

same. Although the total percolation did not differ between treatments in 1998, in May and June of that year, significantly less water percolated ($p=0.001$) from PF than from P-VN and P-N treatments.

Throughout the whole growing period, the pH values of leachates in the P-VN treatments were about 4; in PF and P-N treatments the values were slightly higher, about 4.5 (data not shown). Until July the EC values in the leachates of all treatments were 2 to 3 mS $cm^{-1}$. In July, however, the EC values decreased to 0.2 to 0.4 mS $cm^{-1}$ and in autumn they were 0.1 to 0.2 mS $cm^{-1}$ (data not shown).

## Nitrogen and phosphorus concentrations in leachates and soil waters

The N concentrations in the leachates of all treatments were highest in May and June. In 1997 in leachates of the PF treatment the total N concentrations were sometimes over 500 mg $l^{-1}$ (Figure 2). During the summer months about half of the total N concentrations consisted of $NO_3$-N and the other half of $NH_4$-N. In autumn, N in the leachates was in organic form.

Soil water contained nitrates and organic N compounds, but little ammonium ($NH_4$-N

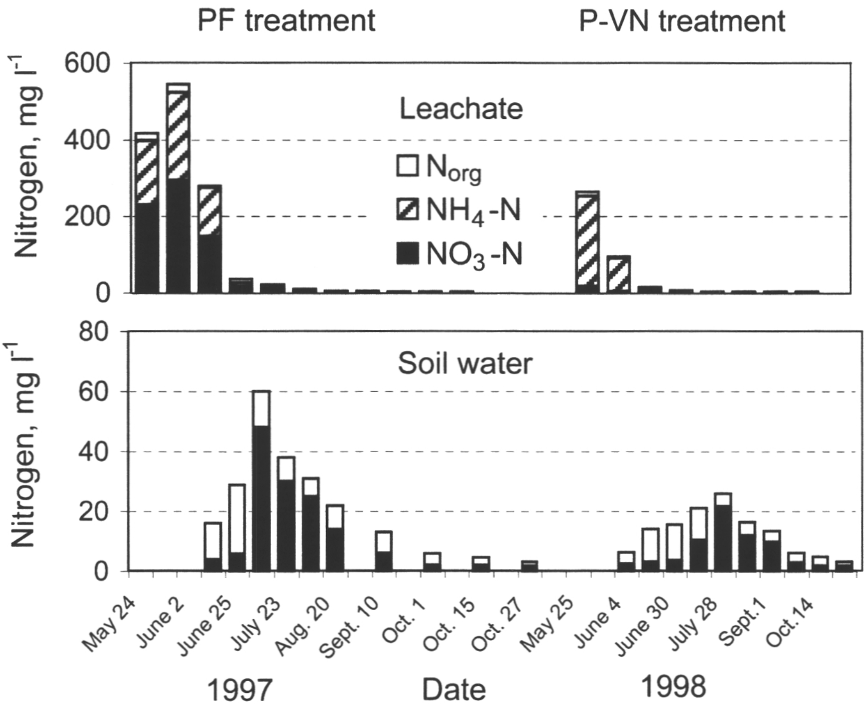


**Figure 2.** Total N concentrations in leachates and soil waters in 1997 (PF treatment = GP fertilizer premixed into peat + fertigation) and 1998 (P-VN treatment = fertilizer "Vital Nursery" premixed into peat).

< 1 mg $l^{-1}$). The total N concentrations in soil waters collected beneath the container area were highest in July. The N concentrations in soil water beneath the PF treatment in 1997 were higher than those beneath the P-VN treatment in 1998 (Figure 2).

The $PO_4$-P concentrations were also highest, from 200 to 400 mg $l^{-1}$, in leachates of the PF and P-N treatments during the greenhouse period (data not shown). Then the concentrations gradually decreased less than 50 mg $l^{-1}$ in July and August and less than 10 mg $l^{-1}$ after September. The concentrations of $PO_4$-P in the leachates of the P-VN treatment were low, in May and June generally less than 50 mg $l^{-1}$ and later less than 10 mg $l^{-1}$. Samples of soil water contained less than 1 mg $l^{-1}$ $PO_4$-P.

## Leaching of nitrogen and phosphorus through containers

Although in the PF treatment the mean amount of leached N (36 kg $ha^{-1}$) was greater than that for the P-VN treatment (24 kg $ha^{-1}$) in 1997, the difference was not significant (p=0.09). In 1998, the mean mount of leached N (9 kg N $ha^{-1}$) for the PF treatment was significantly less ($p< 0.001$) than that for the P-N and P-VN treatments (48 and 46 kg N $ha^{-1}$, respectively). The differences in amounts of leached N between treatments occurred during the first growing weeks, since the N leached mainly (60 to 80%) during May and June (Figure 1). After June the amounts of leached N were the same in all treatments.

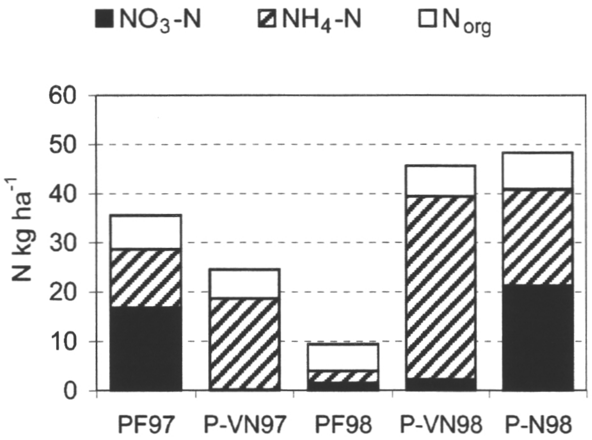


**Figure 3.** Amounts of $NO_3$-N, $NH_4$-N and organic N (kg $ha^{-1}$) in leachates of three treatments. For treatments, see legend in Figure 1.

From P-VN treatment most of the N leached as $NH_4$-N (80%); less than 5% leached as $NO_3$-N (Figure 3). From PF and P-N treatments similar proportions (30 to 40%) of N leached as $NO_3$-N and $NH_4$-N. The rest of the leached N was in organic form.

$PO_4$-P leached significantly less through P-VN treatment in 1997 ($p<0.05$) and in 1998 ($p=0.001$) than through PF and P-N treatments (Figure 1). P did not leach as predominantly during May and June as N did.

**Total load for container birch production**

Separation of the birch container trays increased the growing area twofold, and about half the amounts of N and P in irrigation water were applied outside the container trays. Although in 1998 in the PF treatment the amount of leached N was only 9 kg $ha^{-1}$, the amount of N applied to free spaces was 50 kg $ha^{-1}$, making the total amount of N reaching the ground (the total load) about 30 kg N (50% x 9 kg N $ha^{-1}$ + 50% x 50 kg N $ha^{-1}$) for one hectare of production area for birch. When slow-release fertilizers were premixed into the peat medium, no fertigation was given and no nutrients were irrigated outside the seedlings. The total N and P load was smaller in the P-VN (23 and 10 kg N and P $ha^{-1}$) and P-N (24 and 22 kg N and P $ha^{-1}$) treatments than in the PF treatment (30 and 29 kg N and P $ha^{-1}$).

**Nitrogen and phosphorus uptake by birches**

Due to the favorable weather conditions, seedlings grew taller in 1997 than in 1998 (Table 4). From mid-July 1997 the height growth of P-VN seedlings was retarded compared to that of the PF seedlings (data not shown). The leaf area measured at the end of August and the height and dry mass of the P-VN stems at the end of experiment were significantly smaller than those of the PF stems. In 1998, the stems of the PF seedlings were the shortest and the leaf area the smallest of all the treatments.

In all treatments the N and P concentrations of stems, roots and fallen leaves were higher in 1998 than in 1997 (data not shown). In both years, the N concentration of PF

**Table 4.** Final stem height, root collar diameter and dry mass (DM) of stem and roots and leaf area (mean ± s.d.) in different fertilizer treatments and years. The values marked with different letters differ from each other in this year ($p < 0.05$). For treatments, see legend in Table 1.

| Treatment | Height, cm | Diameter, mm | Stem DM, g | Root DM, g | Leaf area, $cm^2$ |
|---|---|---|---|---|---|
| PF97 | 89±11 a | 6.9±0.5 a | 7.4±1.9 a | 2.0±0.4 a | 521±106 a |
| P-VN97 | 80±8 b | 6.7±0.4 a | 6.2±1.0 b | 2.2±0.3 a | 410±109 b |
| PF98 | 62±7 a | 5.9±0.6 a | 4.0±0.9 a | 1.8±0.5 a | 381±88 a |
| P-VN98 | 64±8 a | 6.0±0.7 a | 4.5±0.7 a | 2.0±0.4 a | 514±134 b |
| P-N98 | 69±10 b | 6.0±0.4 a | 4.6±1.2 a | 1.8±0.4 a | 495±113 b |

**Table 5.** N and P balance with regard to N and P applied and recovered (mg) in seedlings (mean ± s.d.) grown at different fertilizer treatments. For treatments, see legend in Table 2.

| | Treatment | | | | |
|---|---|---|---|---|---|
| | PF97 | P-VN97 | PF98 | P-VN98 | P-N98 |
| | | | N mg seedling$^{-1}$ | | |
| Applied | 110±2 | 173±3 | 101±5 | 214±12 | 249±7 |
| N content of seedlings | 89 ± 12 | 77±6 | 66±8 | 73±2 | 72±1 |
| in stem | 58±9 | 46±4 | 37±7 | 37±2 | 38±3 |
| in roots | 12±3 | 14±3 | 13±3 | 17±2 | 17±1 |
| in fallen leaves | 19±1 | 17 ± 0.4 | 16±1 | 19±2 | 17±1 |
| | | | P mg seedling$^{-1}$ | | |
| Applied | 45±1 | 76±1 | 50±3 | 83±5 | 85±2 |
| P content of seedlings | 16±3 | 16±1 | 13±2 | 15±0.3 | 13±0.5 |
| in stem | 9±2 | 7±0.4 | 5±1 | 6±0.2 | 6±0.2 |
| in roots | 3±0.4 | 3±0.2 | 3±1 | 4±0.3 | 3±0.2 |
| in fallen leaves | 4±1 | 6±0.2 | 5±1 | 5±0.4 | 4±0.5 |

stems (8.2 and 9.2 mg $g^{-1}$ in 1997 and 1998, respectively) was highest, but that of the PF roots (6.0 and 7.7 mg $g^{-1}$ in 1997 and 1998, respectively) was lowest. The N content of the PF seedlings was greatest in 1997, but that of PF seedling was smallest in 1998 (Table 5); the differences between treatments were, however, not significant ($p=0.14$ in 1997 and $p=0.15$ in 1998). If fallen leaves are not collected and removed, the N content of these leaves, which was included in the total N content of seedlings, may cause almost as great N load per hectare as the leached N amounts.

The PF seedlings took up 65 to 81 % but P-VN and P-N seedlings only 29 to 45% of the applied N (Figure 4). When the amount of N applied outside seedlings in the PF treatments was estimated on basis of area and included, the efficiency of N use was 62% and 50% for PF97 and PF98 seedlings, respectively. In all treatments the efficiency of P use was low; the seedlings took up only 15 to 33% of the applied P.

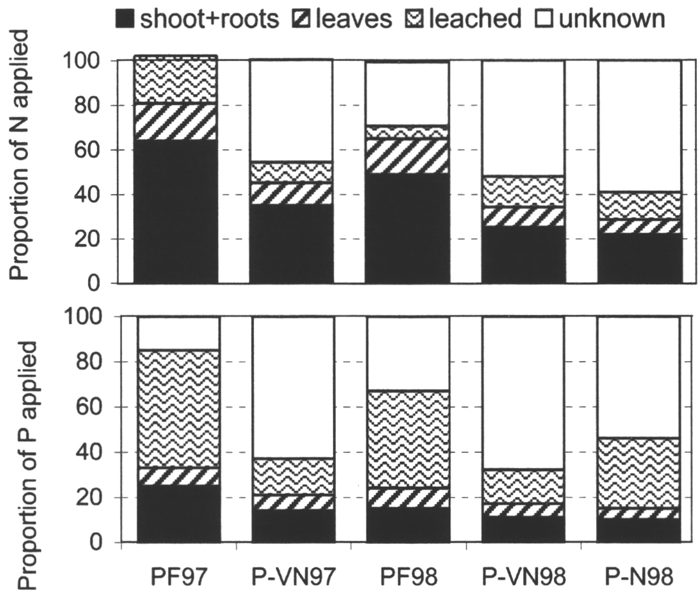


**Figure 4.** Proportion of applied N and P recovered in seedlings (shoots and roots), in fallen leaves, in leachate and the unknown proportion. For treatments, see legend in Figure 1.

# Discussion

When fertilizers were premixed into the growing medium, the first five growing weeks were critical for nutrient leaching in container birch production. The differences in the amount of leached N between treatments arose during these first weeks (Figure 1). The leaching of N depended on how soon after transplanting and how much water percolated through the growing medium. Although the percolated amounts of water were small, the amounts of leached N (15 to 40 kg N $ha^{-1}$) were large, whether or not slow-release fertilizers were used as the nutrient source.

In PF and P-N treatments N was premixed into peat both in soluble and in slow-release form; therefore the origin of the leached N is not known with certainty. Part of the leached N may originate from slow-release fertilizers. Rathier and Frink (1989) found in a study of ornamentals that the greatest proportion of N leached during the first 30 days after fertilization with a mixture of sulfur-coated urea and ureaformaldehyde. Cox (1993) obtained similar results with Nutricote. In the case of Nutricote, the leached nutrients may also originate from damaged fertilizer prills (Huett and Morris 1999).

In contrast to PF and P-N treatments, in the P-VN treatment the main source of leached N was methylene urea. It would be surprising if the total amount of $NH_4$-N leached during the first growing week was mineralized from urea and methylene urea during one week. Apparently some urea and methylene urea had transformed to ammonium already after premixing – either in the peat bales or in containers filled with peat at the end of April. Obviously, when slow-release fertilizers are used, fertilizer should be mixed into the growing medium just before sowing or transplanting.

The fertilizer type influenced the form of the leached N. During both years almost no $NO_3$-N leached from P-VN treatment; on the other hand, about 30% of the total N leached as nitrate from PF and P-N treatments. Nitrate, due to its water solubility, poses the highest risk of contaminating ground water. Ammonium and organic N compounds could, however, increase the risk of ground water contamination, because they could later be transformed into nitrate in the soil (Addiscott et al. 1991, Colangelo and Brand 2001). Although only small amounts of $NO_3$-N leached from the P-VN treatment into the ground, during July and August the concentrations of $NO_3$-N in soil water were greater than 11.3 mg $l^{-1}$. Obviously, some $NH_4$-N was transformed to $NO_3$-N due to nitrification in the soil beneath the P-VN containers.

On the whole, the N concentrations at the same collecting point were smaller in soil water beneath the P-VN treatment in 1998 than beneath the PF treatment in 1997. Evidently, the explanations for the smaller concentrations of N in soil water beneath the P-VN treatment were the very small concentrations of $NO_3$-N in leachates and no fertigation of N between containers. The smaller amount of irrigation in 1998 than in 1997 could also have influenced the difference. The $NO_3$-N concentrations deep in the soil (60 to 90 cm) beneath container-grown horticultural crops have been found to be higher with greater irrigation volumes or leaching fractions (Colangelo and Brand 1997, McAvoy 1994).

Based only on measurements from one growing season, it is not possible to determine whether the use of Vital Nursery fertilizer compared to PF treatment decreases the risk of groundwater contamination. However, the use of apatite as the phosphorus source in P-VN treatment decreased the leaching of $PO_4$-P. The use of slow-release fertilizers decreased the total N and P load per hectare, since no nutrients were fertigated between container seedlings.

The seedlings in all fertilizer treatments fulfilled the Finnish quality requirements for commercial birch seedlings (Rikala 2000). The morphological and chemical properties of the seedlings did not differ greatly between treatments (Tables 4 and 5). The applied amounts of N and P, as recommended by the manufacturers, were about two times greater in the P-VN and P-N treatments than in the PF treatments. The N and P contents of the seedlings were, however, the same, which meant that the efficiency of seedlings in using these nutrients was lower in the P-VN and P-N treatments than in the PF treatments (Figure 4).

A large proportion of N (46 to 59%) and of P (54 to 66%) could not be recovered either in seedlings or in leachates of the P-VN and P-N treatments (Figure 4). Because the nutrients in the peat medium were not analyzed, it is not possible to know whether nutrients still remained in the peat growing medium in the middle of October or whether they (especially N) had volatilized into the atmosphere during the summer and autumn. Obviously, the release of nutrients from the fertilizers used in the P-VN and P-N treatments was so slow in Finnish growing conditions that part of the nutrients had not mineralized (P-VN treatment) or been released from fertilizer prills (P-N treatment) during the growing period.

According to the manufacturer, mineralization of part of the methylene urea in fertilizer Vital Nursery takes more than a year. Mineralization of P from apatite is also a slow process. In addition, the low temperature and pH in the growing medium may have decreased the activity of microbes, in the P-VN treatment, in particular, nitrification seemed to be very slow. Furthermore, the release of soluble nutrients from fertilizer prills could be slower the time stated by the manufacturer. Hincklenton and Cairns (1992) showed that only 42% of the total salts were released from Nutricote Type 100 fertilizer after 17 weeks at constant 25 °C, while 80% of the nutrients should have been released in 100 days. At constant 10°C only 25% of the salts were released.

The slow rate of release means, however, that the amounts of fertilizer applied have to be large enough to guarantee the desired growth of birch seedlings. Apparently the amounts used in this study were nearly the optimum. However, in 1997, when height growth of the seedlings was rapid, compared to fertigated seedlings, the growth of P-VN seedlings was retarded after mid-July. Obviously, the nutrients did not mineralize fast enough.

# Conclusions

Use of slow-release fertilizers instead of liquid fertilization does not necessarily diminish the leaching of nutrients from containers into the ground. The risk for leaching of nutrients is very high at the beginning of the growing period when the nutrient content of the growing medium is high and the uptake by seedlings is low. Very small amounts of percolated water could leach large amounts of N and P. The use of slow-release fertilizers could, however, decrease the total nutrient load per unit area, if container trays or pots are separated during the growing period.

Many factors must be considered when nutrient losses from a container tree-seedling nursery are estimated. First, it is important to identify the sources of nutrient load so that the control measurements are concentrated correctly. Fertigation of nutrients into aisles and other empty spaces around container blocks could cause higher nutrient load than the leaching of nutrients from containers into the ground. When we consider the N load, it seems that, $NO_3$-N analyses are not enough but at least total N analyses is needed. In addition to the analyses of nutrient concentrations, measurements of water volume are needed. Nutrient losses into the nursery environment due to leaching cannot be monitored with precision using the nutrient content of seedlings; with this method, only the magnitude of the risk of leaching can be estimated.

**Acknowledgements**

We thank the staff of Suonenjoki Research Station and Nursery for their co-operation and help during the experiment and the laboratory personal of North Savo Regional Environment Centre for making the chemical analyses. Special thanks to A-M. Veijalainen, M.Sc., and Mr. Jukka Laitinen for technical assistance. We also thank Dr. H. Heinonen-Tanski, Dr. J. Luoranen and Dr. H. Smolander for valuable comments on the manuscript, and Dr. J. von Weissenberg for revising the English language. In addition, we gratefully acknowledge financial support from Pohjois-Savon Liitto and Metsäosaamiskeskus -hanke.

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V

# Leaching of propiconazole and chlorothalonil during production of *Pinus sylvestris* seedlings in containers

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**Abstract:** The risk of environmental contamination by pesticides is not well known in container production of forest seedlings. Leaching of propiconazole (Tilt 250 EC®) and chlorothalonil (Bravo 500®) through peat container medium into the ground was monitored during three growing seasons in nursery production of Scots pine (*Pinus sylvestris L.)* seedlings. Fungicides were applied at about 20-day intervals from end of July until November. The annual load of leached propiconazole (25 to 183 grams active ingredients (a.i) $ha^{-1}$) was higher than that of chlorothalonil (5 to 82 grams (a.i) $ha^{-1}$). The proportion of leached to applied propiconazole was large, 4 to 29%, but less than 1% of the applied chlorothalonil was detected in leachates. The downstream percolation of water in the soil beneath the container area was small. After artificial watering, the detected concentrations of chlorothalonil in soil water 0.5 meter beneath the ground surface were 0.4 to 2.4 $\mu g\ l^{-1}$.

**Key words:** agricultural pollution, fungicide, groundwater, nursery, pesticide

## Introduction

The production of container seedlings has to a large extent replaced the production of bare-root seedlings in Scandinavia (Juntunen & Rikala 2001, Nyström et al. 2001), which has decreased the amounts of pesticides used in forest nurseries (Juntunen 2001, Hannerz & Nyström 2002). The amounts of pesticides applied directly into the ground have also decreased, because most of the pesticide is sprayed on the very densely growing seedlings in container production. The regular irrigation of container seedlings with large volumes of water and on outdoor areas the rainfalls could, however, leach pesticides from seedlings through container medium to the environment. There can be at least local risk of environment contamination by pesticides because some nurseries are situated on areas where groundwater reservoirs form and/or near lakes and rivers.

Chlorothalonil (2,4,5,6-tetrachloroisophthalonitrile, Bravo 500®) was the most used fungicide in Finnish forest nurseries during 1996 growing season (Juntunen 2001). In Finland chlorothalonil was registered only for forest nursery use, but in other parts of world it is used extensively for protection of different crops (Caux et al. 1996, Motonaga et al. 1998). The amount of propiconazole (1-((2-(2,4-dichlorphenyl)-4-propyl-1,3-dioxolan-2yl)methyl)-1H-1,24-triazole, Tilt 250EC®) used in Finnish forest nurseries was only 10% of that of chlorothalonil, but the number of nurseries that used it was almost the same as the number of nurseries, which used chlorothalonil (Juntunen 2001). The large difference in application rates, 2000 g a.i. $ha^{-1}$ for chlorothalonil and 125 g a.i. $ha^{-1}$ for propiconazole, explains the difference in the amounts of these two fungicides used. Propiconazole is also used in Swedish nurseries (Hannerz & Nyström 2002). In addition to forest nurseries it is registered for protection of cereal crops in Finland.

In Finnish container seedling production, the chemical control of Scots pine diseases was most intensive: the control season was longest, the number of pesticide applications was greatest, and the largest doses per hectare were annually applied to the pine seedlings (Juntunen 2000, 2001). Both clorothalonil and propikonazole were registered for controlling Scleroderris canker (*Gremmeniella abietina* (Lagerb.) Morelet) of pine. Chlorotahlonil is a nonsystemic foliar fungicide and it is effective fungicide against broad spectrum of plant pathogens, when propiconazole is systemic and it is one of sterol biosynthesis inhibitor fungicides (Tomlin 1997).

The physico-chemical properties of the active ingredient, such as solubility in water, volatility, soil-sorption tendency and persistence, are used to estimate the leaching potential of the active ingredient (Augustijn-Becker et al. 1994, Tomlin 1997). Besides the characteristics of the active ingredient, in container production the properties of the growing medium and cultural practices influence the fate of the active ingredient in the nursery environment (Landis et al. 1991, Torstensson & Stenström 1995). There are only some studies concerning the leaching of herbicides through media used in container nurseries (Wehtje et al. 1993, Mahnken et al. 1994, Grey et al. 1996), but as far as we know, there are no published results about leaching of pesticides during actual production of container forest seedlings. Therefore the objective of this study was to determine possible leaching of propiconazole and chlorothalonil through peat growing medium into the ground during commercial production of container grown Scots pine seedlings. The concentrations of chlorothalonil in soil water beneath container areas were also measured.

# Material and methods

### Study material and fungicide applications

This field study was conducted in 1996, 1997 and 1998 at Suonenjoki nursery (62°39´N, 27°03´E), where one-year-old Scots pine seedlings were produced according to normal nursery practice (Juntunen et al. 2002). The container types used during the study period were Ecopot containers (PS508; V=103 $cm^3$, 149 pots/tray = 620 pots/$m^2$, Lännen Inc. http://www.lannenplantsystems.com) and hard plastic, Plantek containers (PL81F; V=85 $cm^3$, 81 pots/tray = 546 pots/$m^2$, Lännen Inc.). Sphagnum peat (M6, Kekkilä Corp.Finland) premixed with fertilizer (0.8 kg $m^3$ peat, N16-P8-K16%) was used as the growing medium.

The seedlings were sown in the middle of May and the growing was started in a greenhouse. The fungicide applications (Table 1) began soon after the plastic cover was removed on August 5 in 1996, July 25 in 1997 and July 27 in 1998. The chlorothalonil was applied by irrigation boom mounted with TeeJet 11003VB nozzles. The amount of water applied was 1500 l $ha^{-1}$ and the application pressure 300 kPa. In 1996 the last two applications were carried out with a backpack sprayer (Solo 40123, Solo Kleinmotoren GmbH, Germany).

**Table 1.** Application dates and rates (kg $ha^{-1}$) of chlorothalonil and propiconazole during the years 1996, 1997 and 1998.

| Year and application date | | | Chlorothalonil | | | | Propiconazole | |
|---|---|---|---|---|---|---|---|---|
| | | | Application rate kg a.i. $ha^{-1}$ | | | | | |
| 1996 | 1997 | 1998 | 1996 | 1997 | 1998 G | 1998 N | 1997 | 1998 G |
| 13 Aug. | 31 July | 29 July | 1.5 | 1.5 | 2.3 | – | 0.125 | 0.125 |
| 27 Aug. | 19 Aug. | 19 Aug. | 1.7 | 1.5 | 21.1 | – | 0.125 | 0.375 |
| 13 Sept. | 4 Sept. | 10 Sept. | 2.4 | 1.4 | – | 1.5 | 0.125 | – |
| 24 Sept. | 24 Sept. | 7 Oct. | 1.7 | 1.4 | 1.3 | 1.3 | 0.125 | 0.125 |
| 14 Oct. | 7 Oct. | 29 Oct. | 1.3 | 1.4 | 1.3 | 1.3 | 0.125 | 0.125 |
| 1 Nov. | | | 3.1 | | | | | |
| Total | | | 11.7 | 7.2 | 26.0 | 4.1 | 0.625 | 0.750 |

In propiconazole treatments the containers were sprayed separately, one container at a time. The propiconazole was applied by a special system, which imitated the tractor boom spraying. In this system Teejet 11003VB nozzles were also used and the spraying pressure was the same as in chlorothalonil applications, but the amount of water applied was only 400 l $ha^{-1}$. The recommended dose, 125 g a.i.$ha^{-1}$, was used in every application, except for the accidental threefold dose on August 19, 1998 (Table 1).

In 1996, the leaching of chlorothalonil was monitored from Ecopot containers. In 1997 and in 1998 the leaching of both chlorothalonil and propiconazole was monitored. In 1997, in addition to Ecopot containers, Plantek containers were also used, but in 1998 only Plantek containers. In 1998, the new application schedule (N) was begun for chlorothalonil on September 10, due to the accidental high dose on August 19 in the other schedule (G) (Table 1). The number of replications in each treatment (fungicide, schedule) was two in 1996 and four in both 1997 and 1998.

### Collecting of leachate and soil water

For collecting leachate waters, sloped polystyrene plates (40 x 40 cm or 40 x 60 cm) equipped with a hole and a sampling vessel were placed under container trays before the first fungicide application. The plates were placed systematically among the commercial production stock. The volume and the electronical conductivity (EC) (CDM80, Radiometer, Denmark) and pH (3020, Jenway, England) of leachates were measured daily in 1996 and weekly in 1997 and in 1998. The samples were stored frozen for 4–6 months until fungicide analysis. Collection of leachates continued until the peat growing medium froze.

Soil water was collected using tension lysimeters (P80 ceramic cups, Ceramtec AG) from four points (four cups per point in a square, 0.5 m between cups) at a depth of 0.5 m beneath a greenhouse in 1997 and in 1998. The distance between collection points was about eight meters. Suction was continuous and the pressure in the cups varied from –20 to –60 kPa. The water from each cup was collected into a glass bottle; these bottles were kept in covered boxes. The collection was begun on July 30, 1997, and it was stopped for winter because of freezing (Table 3).

The plan was to collect water from the bottles every second week, but the lysimeters sucked up water poorly, six cups in all, in 1997; and therefore the collecting period was extended to one month. In 1997 the amounts of water collected (2 to 58 ml) from one cup were, however, so small that the water samples of 16 cups from the same time period were pooled into one sample for chlorothalonil analyses (Table 3). In 1998, the soil above the lysimeters was twice watered artificially (at end of May and on August 18). After watering in May, all but two cups collected water during the period from May 15 to June 9, but then in June collection had to stop. Because of water deficit in the soil the lysimeters sucked up air and the pump was working continuously. The collection was begun again on August 18 after watering. For chlorothalonil analyses the soil water from one collecting point (four lysimeter cups) was pooled into one sample (Table 3). The lysimeters were tested on August 28 in 1998, and all except two were working properly.

### Chemical analyses

Water samples (100 ml) were extracted with 20 ml of $CH_2Cl_2$ in a separation funnel (15 min). The $CH_2Cl_2$-phase was then centrifuged to separate the remaining water and suspended material. Extraction was repeated with 10 ml of $CH_2Cl_2$. The $CH_2Cl_2$ was evaporated and the sample was redissolved to a known amount (1 ml) of $CH_2Cl_2$. Samples were analysed with GC-MSD (Hewlett-Packard 5973) using the SIM-technique. The monitored ions were 173, 259, 261, 264, 266 and 268. The run parameters were as follows: splittless injection at 260 °C; oven temperature was programmed from 100 °C at 50 °C $min^{-1}$ to 180 °C (8 min) and finally 50 °C $min^{-1}$ to 280 °C (3 min). Propiconazole and chlorothalonil were quantified with external standards of authentic model compounds. For chlorothalonil the detection limit was 0.1 μg $l^{-1}$ and for propiconazole 0.25 μg $l^{-1}$.

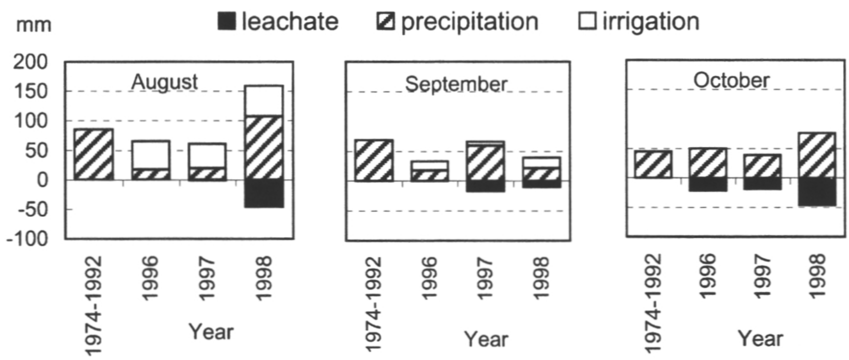


**Figure 1.** Amounts of irrigation, precipitation and leachate (mm) in August, September and October in 1996, 1997 and 1998. The long-term average (1974 to 1992) for precipitation is also presented.

### Precipitation amounts

Autumn 1996 was very dry until mid-October (Figure 1). It also rained very little in August 1997. Autumn 1998 was the most like a normal autumn in terms of amount of precipitation. However, in September 1998 the rainfall was only one third of the normal amount. November 1996 was exceptionally warm, but rainy; it rained almost every day and the total amount of precipitation was 122 mm. The permanent snow cover arrived in November in both 1997 and 1998. The nursery irrigated seedlings with 40–48 mm of water in August, in spite of the large differences in amount of precipitation between years (Figure 1).

### Statistical analyses

The influence of container type on the total amounts of fungicides leached in 1997 was analysed with a t-test using the SPSS Win9.0 program. The influence of year on the total amount of leachate and the total amount of propiconazole leached was also analysed with a t-test. The influence of year on the amount of chlorothalonil leached was not tested because of very different application doses in years 1997 and 1998. The four sample trays per treatment were used as replicates in the analysis, although for practical reasons these trays were placed systematically among the commercial production and they were not true independent replicates.

## Results

### Percolation of water

The amount of precipitation influenced the water amounts percolated (Figure 1). In 1996 as much leachate water was collected during the last days of October and in November (114 mm) as during the whole autumn 1998 (105 mm) (Table 2). In 1997, the mean amount of leachate was 40 mm for Plantek containers and 42 mm for Ecopots. However, the amounts varied considerably among individual Ecopot containers, the minimum being 12 mm and the maximum 83 mm.

The EC of leachates decreased during autumn, and this decrease was dependent on the water amounts percolated. Only small amounts of water percolated through containers before November 1996, and EC values as high as 200 $\mu S\ cm^{-1}$ were measured. In 1998, when much greater amounts of water percolated in August, the EC values were less than 100 $\mu S\ cm^{-1}$ at the beginning of September. In contrast to EC, the pH values of the leachates increased during the autumn. At the beginning of August the pH values were about 4.5, and during last collecting dates they were 5.5.

### Leaching of fungicides

Propiconazole leached far more than chlorothalonil did (Table 2), in spite of the smaller application rate for propiconazole. Thus a total 17

**Table 2.** Amounts of leachate and leached chlorothalonil and propiconazole (mean ± s.e.) in the years 1996, 1997 and 1998.

| Year | Leachate mm | Leachate mm | Leached chlorothalonil g ha$^{-1}$ | Leached chlorothalonil g ha$^{-1}$ | Leached propiconazole g ha$^{-1}$ | Leached propiconazole g ha$^{-1}$ |
|---|---|---|---|---|---|---|
| 1996* | Ecopot A | Ecopot B | Ecopot A | Ecopot B | | |
| Total | 125 | 103 | 6.9 | 81.9 | | |
| % applied | 46 | 38 | 0.1 | 0.7 | | |
| 1997† | Plantek | Ecopot | Plantek | Ecopot | Plantek | Ecopot |
| Total | 40 ± 1 | 42 ± 14 | 10.3 ± 1.0 | 5.3 ± 2.8 | 183.1± 32.1 | 24.6 ± 10.6 |
| % of applied | 24 | 25 | 0.1 | 0.1 | 29.3 | 3.9 |
| 1998‡ | Plantek G | Plantek N | Plantek G | Plantek N | Plantek G | |
| Total | 105 ± 3 | 42 ± 3 | 24.4 ± 1.2 | 12.3 ± 3.0 | 117.8 ± 8.2 | |
| % of applied | 38 | 47 | 0.1 | 0.3 | 15.7 | |

* There were two Ecopot (PS508) containers, A and B
† For both fungicides there were two container types, Plantek (PL81F) and Ecopot (n = 4)
‡ For chlorothalonil there were two application schedules, G and N, (see Table 1) but for propiconazole only one, G (n = 4).

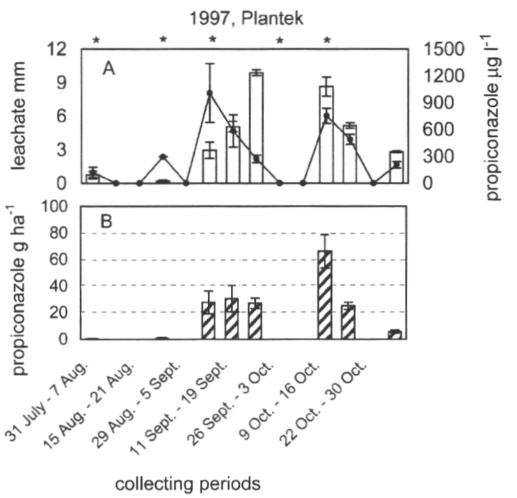


**Figure 2.** Weekly amounts of leachate (mm, columns), and concentrations of propiconazole (µgl$^{-1}$, line and dots) (Fig. A) and amounts of leached propiconazole (g ha$^{-1}$, columns) (Fig. B) for Plantek containers (n = 4, error bars = s.e.) in 1997. Fungicide applications are marked with stars on Fig. A.

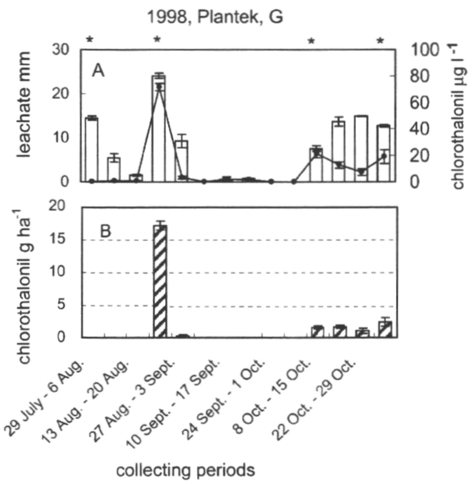


**Figure 3.** Weekly amounts of leachate (mm, columns), and concentrations of chlorothalonil (µgl$^{-1}$, line and dots) (Fig, A) and amounts of leached chlorothalonil (g ha$^{-1}$, columns) (Fig. B) for Plantek containers (n = 4, error bars = s.e.) in 1998. Fungicide applications are marked with stars on Fig. A, on August 19 a tenfold dose was given accidentally.

to 30% of the applied propiconazole leached through Plantek containers, but less than 1% of the applied chlorothalonil leached through container peat medium into the ground during all the years monitored. In 1997 and 1998, the leaching patterns were similar for both fungicides (presented in Figure 2 for propiconazole and in Figure 3 for chlorothalonil).

In general, more fungicides leached through Plantek containers than through Ecopot containers. This difference was significant ($p < 0.05$) for propiconazole in 1997. The amounts of propizonazole leached through Plantek and Ecopot containers were 183 g ha$^{-1}$ and 25 g ha$^{-1}$, respectively. Although the amount of percolated water was significantly (p=0.000) greater in 1998 than

**Table 3.** Chlorothalonil concentrations in soil waters in 1997 and in 1998. Pooled = the water samples of 16 cups from the same period were pooled into one sample for chlorothalonil analyses.

| Period | Chlorothalonil µg $l^{-1}$ point 1 | point 2 | point 3 | point 4 | pooled |
|---|---|---|---|---|---|
| 1997 | | | | | |
| 30 July–28 August | | | | | * |
| 28 August–25 Sept. | | | | | * |
| 25 Sept.–27 Oct. | | | | | * |
| 1998 | | | | | |
| 15 May–9 June | * | * | * | * | |
| 9 June–17 Aug. | † | † | † | † | |
| 18 Aug.–3 Sept. | * | * | * | * | |
| 3 Sept.–24 Sept. | * | 0.4 | 2.4 | 0.5 | |
| 24 Sept.–30 Oct. | * | 0.8 | † | † | |
| 30 Oct.–9 Nov. | * | † | † | † | |

* less than the limit of detection 0.1 µg $l^{-1}$
† no water was collected

in 1997, the amounts of leached propiconazole did not differ significantly (p=0.13) between years (Table 2).

Fungicide concentrations in leachate waters were usually highest after fungicide application and decreased before a new application (Figure 2 and 3). In 1996, the concentrations of chlorothalonil in leachates of container A decreased much sooner than those of container B. The fungicide concentrations did not correlate with the amount of percolated water, and the repeated applications did not increase the concentrations of fungicide in the leachates.

In 1997, the highest concentrations of chlorothalonil in the leachate of an individual container were measured, 722 µg$l^{-1}$ for an Ecopot and 88 µg$l^{-1}$ for a Plantek container. Usually, however, the concentrations were less than 100 µg $l^{-1}$. The variability of the samples collected on the same date was large for Ecopots and small for Plantek containers. In 1998 the accidentally applied large dose (on August 19) increased the chlorothalonil concentrations for a week (Figure 3).

The propiconazole concentrations were much higher in leachates of Plantek containers than in those of Ecopot containers in 1997. The leachates of some Plantek containers had over 1000 µg $l^{-1}$ of propiconazole in September (Figure 2), at which time the highest concentration measured in leachate of one Ecopot container was 460 µg $l^{-1}$. In 1998 in leachates of Plantek containers the concentrations were almost one order of magnitude lower than in 1997. In 1998 the highest measured concentration of propiconazole was 409 µg $l^{-1}$.

### Chlorothalonil in soil water

In 1997 only three pooled samples were analyzed, and all of these had a chlorothalonil concentration less than the limit of detection, 0.1µg $l^{-1}$ (Table 3). In September and October 1998 chlorothalonil was found in the soil waters of three collecting points. The highest value was 2.4 µg $l^{-1}$.

## Discussion

According to our results, the fungicide load into the ground decreased when Scots pine seedlings were grown in containers. When the annual application rate of chlorothalonil was as high as 4.1 to 26 kg (a.i) $ha^{-1}$ (Table 1), the amounts of chlorothalonil leached through container medium were 5 to 82 grams (a.i) $ha^{-1}$ (Table 2), i.e. less than 1% of the applied chlorothalonil was detected in leachates. The annual load of leached propiconazole was greater than that of chlorothalonil. The leached amounts of propiconazole were 25 to 183 grams (a.i) $ha^{-1}$ (Table 2), although the applied amounts of propiconazole were small, 0.62 to 0.75 kg (a.i) $ha^{-1}$ (Table 1), which meant that the proportion of leached to applied propiconazole was large, 4 to 29%. The total doses applied in these experiments were almost the same as the mean doses applied by Finnish nurseries in 1996 (Juntunen 2001).

The fungicides were applied to densely growing seedlings (546 to 620 seedlings per $m^2$), which meant that only part of each application dose reached the peat growing medium. When the seedling height and needle mass (area) increased during the growing period, a smaller amount of fungicide went on the peat medium directly. Obviously, the processes both on seedlings and in peat growing medium influenced to the amounts leached into the ground.

The studied fungicides are used to control diseases on shoots and needles; and to be effective, they should remain on the needles as long as possible. The half-life of these fungicides might, however, be much shorter on needles than in soil. Elliot and Spurr (1993) reported that chlorothalonil had a mean half-life of 14 days on the leaves of peanuts, but the mean half-life has been only 7 days on potato canopy (Bruhn & Fry 1982). Reports about the half-life of propiconazole on leaves could not been found. Volatilization, biological and photochemical degradation, and adsorption by seedling tissues can influence to the persistence of pesticides on leaves.

The loss of chlorothalonil from potato foliage increased with increasing mean daily temperatures; Bruhn & Fry (1982) connected this loss to the volatilization. Since the pesticides, in general, have low vapour pressure, volatilization has been regarded as being of little importance for residue decline. However, there are studies that the volatilization of pesticides from plant surfaces, and also from soil surfaces, has been greater than assumed earlier (Scheunert 1992, Hüskes & Levsen 1997, Da Silva et al. 2001).

Irrigation and rainfall remove these fungicides from shoot and needles into the growing medium. Bruhn & Fry (1982) have shown that rainfall removed cholorothalonil from the leaves of potatoes; the sooner after application the rainfall occurred, the greater was the removal. Because of the higher water solubility of propiconazole compared to that of chlorothalonil, 100 and 0.9 mg $l^{-1}$ (Tomlin 1997), respectively, the removal of propiconazole from needles could have been even greater than that of chlorothalonil. Tuomainen et al. (1999) found no propiconazole on pine needles at the eighth day after application, but about 30–50% of the chlorothalonil deposit measured after application was determined on the needles after two weeks.

Although there was not always rainfall and leaching of water after pesticide applications, a trend could be seen: fungicide concentrations in leachates were usually highest after pesticide application and decreased before a new application (Figures 2 and 3), and repeated applications did not increase the concentrations of pesticides in the leachates. Obviously, the adsorption of fungicides to peat and the degradation decreased the concentration of both fungicides in leachates when time passed. In laboratory experiments, adsorption of herbicides, oxadiazon and metolachlor, has been over 90% in peat medium (Wehtje et al. 1993, Grey et al. 1996).

We do not know what the role of degradation was in peat medium, because the metabolites of fungicides in leachates were not measured. According to the literature, the half-life of chlorothalonil in soil varies from a few days to two months (Tomlin 1997, Cox 1997). In laboratory conditions, however, in two different soils the rate of degradation of chlorothalonil has been shown to decrease after the second application (Katayama et al. 1991). Apparently, accumulation of the metabolite TPN-OH (4-hydroxy-2,5,6-trichloroisophthalonitrile) has been the reason for the suppressed degradation of chlorothalonil (Motonaga et al. 1998). The degradation of propiconazole is not so well known as that of chlorothalonil. The half-life of propiconazole in soil may be longer, from 40 to 70 days (Tomlin 1997), than that of chlorothalonil.

It is difficult to know wheather the higher water solubility of propiconazole was the only reason to the greater leaching of propriconazole compared to chlorothalonil, or did the other processes on needles and peat medium effect to the leaching. In agricultural field studies propiconazole has also been found in both runoff and drainage waters (Eklo et al. 1994, Laitinen 2000). Both fungicides leached more through Plantek containers than trough Ecopot containers. We speculate that the shape of the individual cavities in trays may explain the difference; the cavities of Plantek containers decrease in diameter toward the bottom, and there is empty space between cavities. The water may have percolated from the upper part of cavities and flowed down onto the surface of the cavities. Therefore the fungicide could have leached through a thinner layer of peat than in the Ecopots.

Chlorothalonil concentrations in leachates were always less than 1000 µg $l^{-1}$ and usually less than 100 µg $l^{-1}$, although the concentrations of chlorothalonil in application water varied from 1000 to 2500 mg $l^{-1}$ (as high as 11 000 mg $l^{-1}$ in the large dose in August 1998). The propiconazole concentration in the application water was about 300 mg $l^{-1}$, but in leachates the concentrations varied from 100 to 500 µg $l^{-1}$. Although the concentrations of both fungicides were diluted many-fold, when the fungicides leached through peat medium, the concentrations were still high in leachates compared with the concentrations allowed in drinking water. According to the EU directive the limit for individual pesticide in drinking water is 0.1 µg $l^{-1}$ and for the total sum of all pesticides 0.5 µg $l^{-1}$ (European Community 1998). Chlorothalonil concentrations in soil water (0.4 to 2.4 µg $l^{-1}$) were at the same level as the limit value.

The lysimeters sucked up water poorly. Obviously, complete container tray cover and the small amounts of leachate caused a small hydrological load of water, and the downstream flow of water beneath containers was small. The reasons for the small amount of leachates were the long periods in the greenhouse and irrigation method used (Juntunen et al. 2002). During the outdoor periods, the amounts of precipitation were also smaller than the long time averages for precipitation. It seems that the risk for ground water contamination was small in these circumstances. In autumn, heavy and long-lasting rainfall can, however, increase leaching and runoff. Both chlorothalonil and propiconazole are toxic to aquatic animals, therefore the nurseries located near a river or a lake should be aware about the possible contamination risk. The influence of rain could be controlled, e.g. by covering the outdoor growing areas.

In conclusion, the seedling canopy and the peat medium in containers effectively decreased the load of chlorothalonil and propiconacole into the ground when Scots pine seedlings were grown in containers. The container type and the active ingredient, however, influenced to the amounts of active ingredient leached through containers. More studies with different pesticides used on the different seedlings and growing media are needed before it will be possible to say with certainty that the container production of forest seedlings has decreased the contamination risk of environment caused by pesticides.

**Acknowledgements**

We thank the staff of Suonenjoki Research Nursery and Station for good cooperation during the experiment. Special thanks to M. Maukonen, M.Sc. , A-M. Veijalainen, M.Sc. and Mr. P. Karppinen for technical assistance. We also thank Dr. H. Heinonen-Tanski, Dr. A. Lilja, Dr. H. Smolander and R. Silvo, M.Sc. for valuable comments on the manuscript, and Dr. J. von Weissenberg for revising the English language. We gratefully acknowledge financial support from Metsämiesten Säätiö.

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ISBN 951-40-1829-X
ISSN 0358-4283