ENVIRONMENTAL IMPACTS OF NURSERIES

MARJA-LIISA JUNTUNEN

Marja-Liisa Juntunen is with the Finnish Forest Research Institute, Suonenjoki Research Station, Juntintie 40, FIN-77600 Suonenjoki, Finland; telephone: 318.17.513811; email: marja-liisa.juntunen@metla.fi

Juntunen M-L. 2003. Environmental impacts of nurseries. In: Riley L.E., Dumroese R.K., Landis T.D., technical coordinators. National Proceedings: Forest and Conservation Nursery Associations—2002. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station. Proceedings RMRS-P-28: 64–73. Available at: http://www.fcnanet.org/proceedings/2002/ juntunen.pdf

Abstract

Forest seedling production could be seen from at least 2 environmental standpoints: nurseries as possible point sources of harmful chemicals, and as part of the artificial regeneration process in life cycle analyses of wood products. If nurseries are looked upon as point sources of agricultural pollution, then the harmful substances of importance to human health and the environment are nitrogen and phosphorus compounds, as well as pesticides and their metabolites. The handling of bio-wastes could indirectly influence the pollution potential of nurseries. For example, effective waste management and good nursery hygiene could decrease the risk of diseases and the need for chemical control.

Evaluation of production systems and methods could help nurseries to develop growing practices that decrease the nutrient and pesticide load on the environment. Many factors must be considered when nutrient and pesticide losses from a container tree seedling nursery are estimated. For example, it is important to identify the sources of nutrient and pesticide 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. 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 impact.

Key Words

Fertilizer, groundwater, eutrophication, fertilizer efficiency, container nursery, leachate, Scots pine, *Pinus silvestris*, Norway spruce, *Picea abies*, silver birch *Betula pendula*

INTRODUCTION

Ground water pollution and eutrophication of surface waters due to agricultural practices have been reported worldwide. Still, the risk posed by production of forest tree seedlings, although 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, since some nurseries are situated on areas near lakes and rivers and/or where ground water reservoirs are found.

Use of chemical fertilizers has increased the amount of nitrogen (N) and phosphorus (P) transferred from agricultural fields to surface and ground waters (Tiessen 1996; Vitousek and others 1997). Excess P, in particular, and N in the surface water has accelerated the eutrophication of these waters. Small shallow lakes, typical in Finnish agricultural regions, are most sensitive to eutrophication (Kauppi and others 1993). In the European Union (EU), NO_3 levels greater than 50 mg/l (= NO_3-N 11.3 mg/l) in drinking water are considered unsafe for humans (European Community 1998). In the US, the NO_3-N limit is 10 mg/l (USEPA 2001). High nitrate concentrations in drinking water could affect, in particular, the health of infants.

Pesticides are a heterogeneous group of chemicals, and their risks to human health and environment vary greatly. According to Gallivan and others (2001), the health and environmental risk is a function of the toxicity of the pesticide and the level of exposure. Risk characterization defines the likelihood that humans or wildlife will be exposed to hazardous concentrations. For example, in the EU, the guideline limit for an individual pesticide in drinking water is 0.1 μg/l. The total limit for all pesticides is 0.5 μg/l (European Community 1998).

Not only in Finland, but also in Norway, Sweden, and 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.

Information about the impacts of forest nurseries is needed for the environmental management work of nurseries and for life-cycle analyses of wood products (fig. 1). This article is a short summary of studies carried out in the Finnish Forest Research Institute, Suonenjoki Research Station and nursery during the years 1995 to 1998. The main aims of these studies were to survey the environmental impact of forest seedling production by surveying the use of fertilizers and pesticides in Finnish forest nurseries and assessing how much is leached into the ground in production of container seedlings.

Materials and Methods

Questionnaire-based Survey

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 first part dealt with the number of seedlings grown and the areas, equipment, and growing methods (Juntunen and Rikala 2001). In the second part of the questionnaire, more detailed questions were asked about cultivation practices and the schedule of the largest container seedling lots, for example sowing dates, period in the greenhouse, and dates of fertigation and fertilizer doses (Juntunen and Rikala 2001). For pesticides, such information as application dates, trademarks of the pesticides used and the doses used per hectare was collected (Juntunen 2001). 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).

Leaching Studies

The leaching of N and P and 4 pesticides from peat growing medium in containers was monitored in commercial forest seedling production at Suonenjoki nursery in 1995 to 1998. The water percolated from container medium was collected with the same system in all experiments from May to October/November. Sloped polystyrene plates (16 x 16 inch or 16 x 24 inch [40 x 40 cm or 40 x 60 cm]) equipped with a hole and a sampling vessel were placed under container trays (fig. 2). The trays were placed systematically among the commercial production stock. The volume, electrical conductivity (EC), and pH of leachates were measured daily (excluding

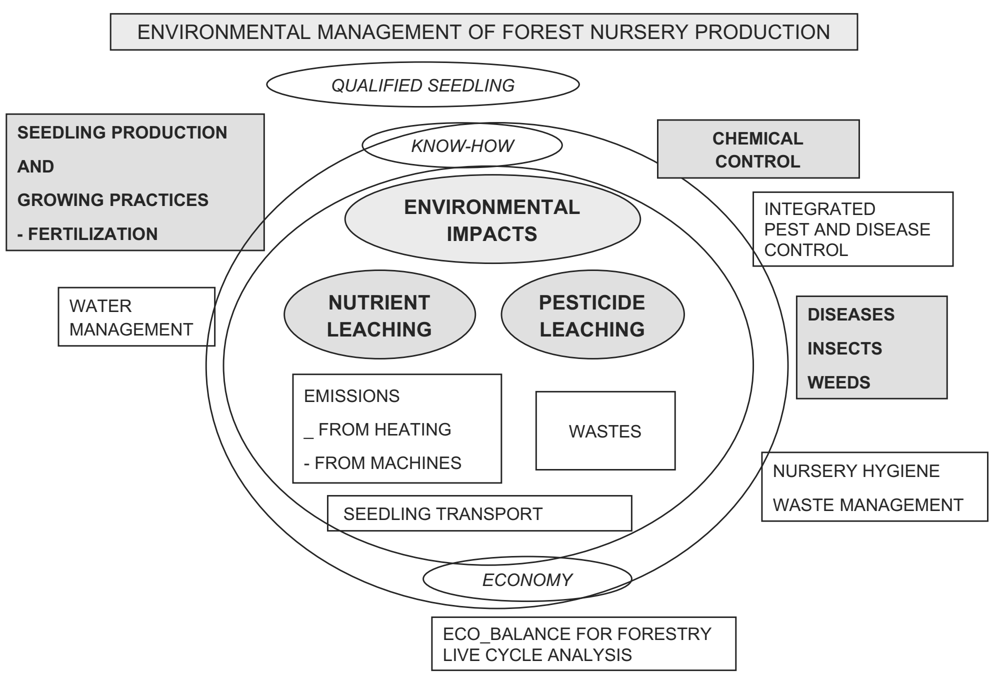

Figure 1. Environmental impact of forest tree nurseries and some influencing factors.

Figure 2. Leachate collector with plate and vessel. One-year old Norway spruce seedlings in Plantek 81F container tray. (Photographed by Pekka Voipio)

Saturday and Sunday) in 1995, and weekly in other years. The samples were stored frozen for 4 to 6 months until analyzed for nutrients or pesticides.

Soil water was collected using tension lysimeters (P80 ceramic cups). The lysimeters were installed at a depth of 1.6 ft (0.5 m) beneath 2 greenhouses in 1996 and 1997. The birch greenhouse included 16 lysimeters collecting water from 3 different points and the pine greenhouse another 16 lysimeters collecting water from 4 different points.

In the first study, the leaching of N and P from peat medium in containers into the ground and the nutrient uptake of seedlings were investigated in commercial production of Scots pine (*Pinus silvestris* L.), Norway spruce (*Picea abies* Karst.) and silver birch (*Betula pendula* Roth) (Juntunen and others 2003a).

In the second study, N and P leaching and uptake by container silver birch seedlings were measured when 2 different types of slow-release fertilizers were used in the commercial growing of seedlings (Juntunen and others 2003b). The source of N in the fertilizer "Vital Nursery" ("Taimiston Kestolannos" Kemira Corp., Finland) 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. The other fertilizer used in this study was Nutricote® T70 (Nichimen Corp, Japan). The N and PO_4-P concentrations in soil water beneath the container area were also measured.

In the third study, possible leaching of pesticides, propiconazole (Tilt 250 EC®) and chlorothalonil (Bravo 500®), from peat growing medium into the ground was determined during commercial production of container Scots pine seedlings (Juntunen and Kitunen 2003). The concentrations of chlorothalonil in soil water beneath the container areas were also measured.

In the fourth study, the leaching of pesticides, triadimefon (Bayleton 25®) and (alpha-)cypermethrin (Ripcord® and Fastac®), was studied in container birch production, and only a part of this data has been published (Juntunen 2002).

Results and Discussion

Use of Fertilizers and Pesticides

Per each shipped bareroot seedling, nurseries used about 8X more N, 5X more P and 4X more pesticides than used for each shipped container seedling. Most container seedlings were delivered for planting as 1-year-old seedlings, when most of the bareroot seedlings were 4-year-old seedlings. In Sweden, nurseries have applied even more nutrients to bareroot seedlings than in Finland (Nyström and others 2001).

The survey nurseries used 385,800 lb (175,000 kg) 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, 1460 lb (662 kg) ai, was used in bareroot production and the other half in container production. In Sweden, the southern nurseries produced more bareroot seedlings and used more pesticides compared to the northern nurseries, which mainly produced 1-year-old container seedlings (Hannerz and Nyström 2002).

During the last 20 years, the annual use of fertilizers in Finnish forest nurseries has decreased from about 1,763,700 to 441,000 lb (800,000 to 200,000) kg ai, and the use of pesticides from about 39,000 to 2200 lb (18,000 to 1,000 kg) ai. The main reason for the decrease has been the increased proportion of container production. In conclusion, an average Finnish nursery used 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.

Great Variation among Nurseries in Use of Nutrients and Pesticides in Container Production

The amounts of N and P applied in fertigation varied greatly between nurseries (fig. 3). The nursery with the greatest use of fertilizers applied about 6X more N and P than the nursery with the smallest use of fertilizers. Often there were 1 or 2 nurseries that differed from most of the nurseries. Depending of tree species, the nurseries applied, on an annual average, 143 to 205 lb N/ac (160 to 230 kg N/ha) and 62 to 89 lb P/ac (70 to 100 kg P/ha), when the amount of nutrients applied in premixed fertilizer were included. Tree species had little influence on the mean amounts of nutrients premixed and fertigated per unit area. Because of the different growing densities, the mean amounts of N applied per seedling grown in a container were 145, 46, and 36 mg for 1-year-old birch, spruce and pine, respectively.

The Finnish survey nurseries used 7.5 lb (3.4 kg) ai pesticides per million shipped container seedlings and (32.4 lb (14.7 kg) ai per million shipped bareroot seedlings. The variation in pesticide use between individual nurseries was great. The Swedish studies have given the same result (Hannerz and Nyström 2002). The mean amounts of pesticide use were greatest for pine seedlings (8.5 lb/ac [9.5 kg/ha]) and smallest for spruce seedlings (0.8 lb/ac [0.9 kg/ha]). The largest number of products was used in growing Scots pine seedlings. The number of pesticide applications was greatest, and the chemical control season was longest for growing pine. Scots pine, in particular, has many nursery diseases (Lilja 1986; Lilja and others 1997; Juntunen 2000).

The reasons for differences in fertilization and in chemical control cannot be analyzed in a survey study. The published data, however, give individual nurseries the possibility to compare their practices and the amounts of chemical applied with the amounts used in other nurseries and could thus provide the impetus for evaluation and development of growing practices.

Percolation of Water from Container Trays

In the Finnish system of container seedling production, the outdoor time was critical for amounts of leachate. Depending on tree species, a total of 1 to 7 inches (25 to 175 mm) water, that is 11% to 31% of the applied water (irrigation + precipitation), percolated from the trays. During the greenhouse period, percolation was < 10%. In the autumn, however, 50% to 70% of rainwater leached through the trays. During the greenhouse period, the water content of peat medium could be maintained inside the optimum level; but in August and later in autumn, when evapotranspiration decreased, the water content of peat medium increased permanently to high levels (fig. 4).

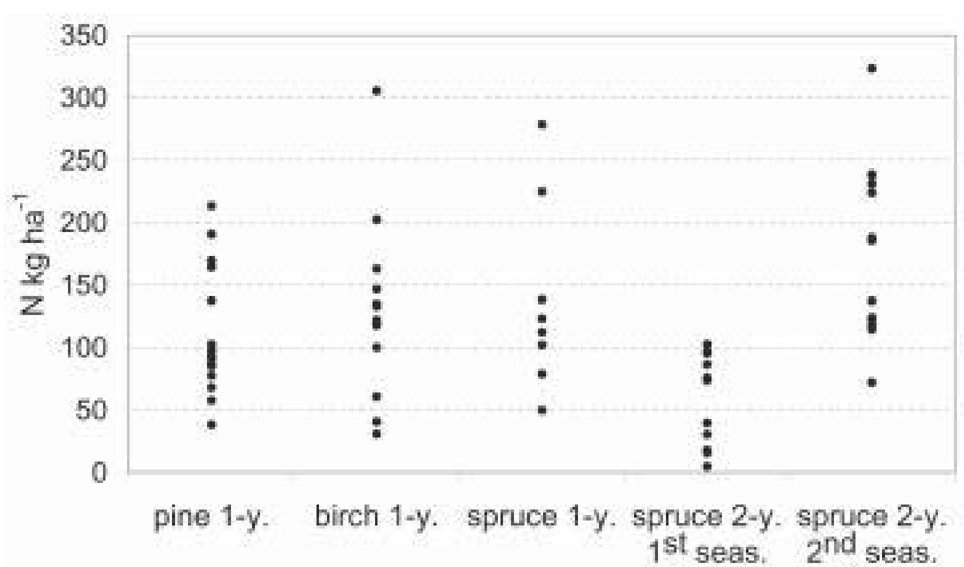

Figure 3. Amounts of nitrogen applied by nurseries to container seedlings in fertigation. Each dot represents one nursery.

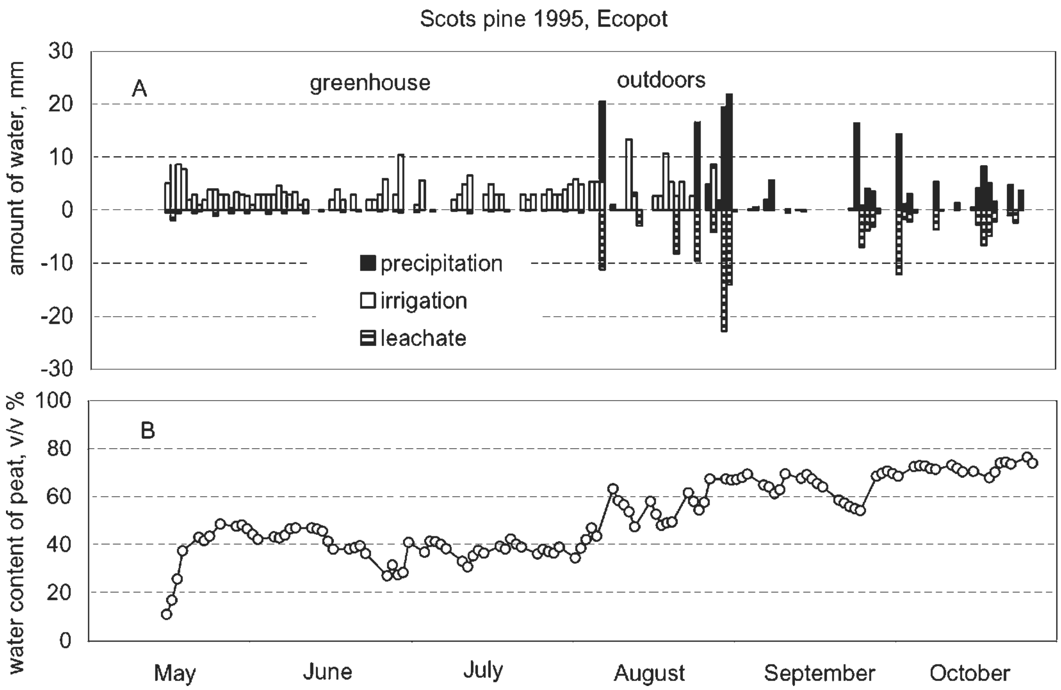

Figure 4. A) Amounts of water applied (irrigation + precipitation) and the amounts of leachate (mm) produced daily (excluding Saturday and Sunday) in production of container Scots pine seedlings in 1995; B) Water content of peat medium as a proportion of the peat volume in container trays.

The irrigation (fertigation) method used in Finnish forest nurseries was based originally on the studies of Puustjärvi (1977) and is discussed by Heiskanen (1993) and confirmed by Heiskanen (1995). According to their conclusions, the water availability and aeration are optimum for the growth of tree seedlings when the water content of the light *Sphagnum* peat medium in containers is at the level of 40% to 50% of the peat medium volume. Lamhamedi and others (2001) have also concluded that a water volume of 30% to 45% of peat-vermiculite (3:1 v:v) substrate volume in large containers (21 in^3 [350 cm^3]) is optimum for the growth of white spruce seedlings.

In Dumroese and others (1995), the amounts of discharged water were as large as 450 to 800 mm. The different irrigation (fertigation) methods could explain this difference. Dumroese and others (1995) irrigated according to recommendation of Landis and others (1989): “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.” The greater the leachate fraction is, the greater is the risk of nutrient contamination of the environment (McAvoy and others 1992).

Water management is an important means of controlling contamination of the environment, because water carries both nutrients and pesticides (Landis and others 1991). Water management includes 2 aspects: the reduction of the amounts of water discharged in seedling production, and the management of waste water.

Leaching of Nutrients

The annual leaching of N in the production of container forest tree seedlings (fig. 5) was not much greater than the mean losses of N, about 16 to 18 lb/ac (18 to 20 kg/ha), from Finnish agricultural fields (Rekolainen and others 1993). The P leached in substantially greater amounts (10 to 50 lb/ac [11 to 56 kg/ha]) than what had been measured from agricultural fields, which was 0.85 to 1.5 lb/ac (0.95 to 1.7 kg/ha) (Rekolainen and others 1997). Although the results for amounts of N and P leached are only from one nursery, it was fairly representative of most forest nurseries in Finland.

The premixing of fertilizer into the peat growing medium can increase the leaching risk of nutrients. When the nutrient content of peat is large at the beginning of seedling growth, the irrigation can

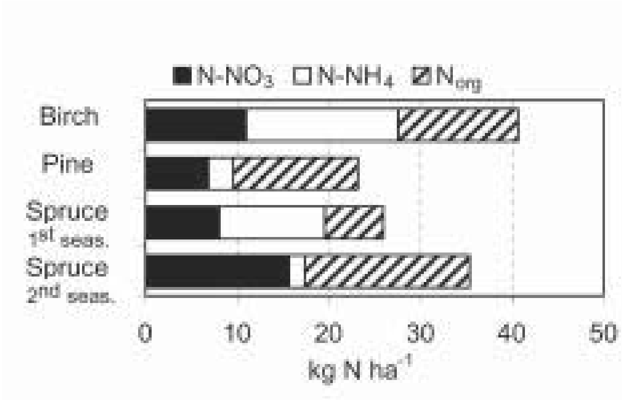

Figure 5. Leached amounts of NO_3-N, NH_4-N and organic N by tree species in 1995.

cause nutrient leakage. 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. On the basis of the leaching study, the use of slow-release fertilizers instead of fertilization used in Finnish nurseries does not necessarily diminish the leaching of N from containers into the ground in birch production.

About 50% to 90% of the N leached from conifer trays during July and August (during the fertigation period). The number of fertigations, 3 to 8 sessions during the growing season, was very low. 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 (0.4 inch [10 mm]) that occurred soon after 1 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 N leached in nitrate, ammonium, and organic N form from peat growing medium (fig. 5). The N forms, ammonium, urea, and methylene urea, premixed into the peat and applied with fertigations may explain the amounts of NH_4-N in the leachates. 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 and others 1991; Colangelo and Brand 2001). Apparently NO_3-N analyses are not enough; when the risk of contamination is evaluated, total N analyses are also needed.

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 Finnish pine and spruce production, the container trays usually cover the whole production area; that is, the fertigation falls outside containers only around the blocks of container trays. In a greenhouse (164 ft x 36 ft = ~5900 ft^2 [50 m x 11 m = 550 m^2]) the irrigation could overlap the area covered by container trays from 1.6 to 5 ft (0.5 to 1.5 m) (the middle aisle and sides), which means that from 10% to 20% of the nutrients are applied outside the 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 (9 and 10 lb N/ac [17 and 18 kg N/ha], respectively).

In birch production, the situation is different because most nurseries placed the birch container trays about 8 inches (20 cm) from each other before fertigations started. Due to tray separation, the container trays covered only about half of the total irrigation area; that is, 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, 78.5 lb N/ac (88 kg N/ha), than that caused by the amounts of N leached, 18 lb N/ac (20 kg N/ha).

When slow-release fertilizers were premixed to peat growing medium, no fertigations were given in birch production; that is, no nutrients were applied outside the container trays. The amounts of N that leached from container trays caused the total load.

Soil Water Beneath Pine and Birch Container Areas

The different lay-out of pine and birch containers in greenhouses, after birch containers were placed 8 inches (20 cm) apart at the end of June, influenced the leaching of water and nutrients in the soil beneath the containers.

In pine production, the small amounts of leachate, and complete container tray cover, caused a small hydrological load. From May to July, these leachates were less than 0.4 inch (10 mm) per month, and from August to October, less than 4 inches (100 mm) per month. In these conditions, the downstream flow of water beneath containers was small, which was noted in the amounts of water collected by lysimeters. In

1997, the lysimeters took up water poorly (only 6 cups total). In 1998, some water samples were collected when the soil above the lysimeters was watered twice artificially.

Beneath the birch container area, the situation was different. Separation of the containers increased the hydrological load. For example, in July the applied amount of water on the ground without container cover was 12 inches (300 mm), while the leached amount was only 2 inches (50 mm). The increased N load and irrigation volume increased both the water volumes collected by ceramic cups and the N concentration in soil water (fig. 6). The soil water contained nitrate and organic N compounds, but little ammonium (NH_4-N < 1 mg/l). The concentrations of PO_4-P were also less than 1 mg/l in all soil water samples.

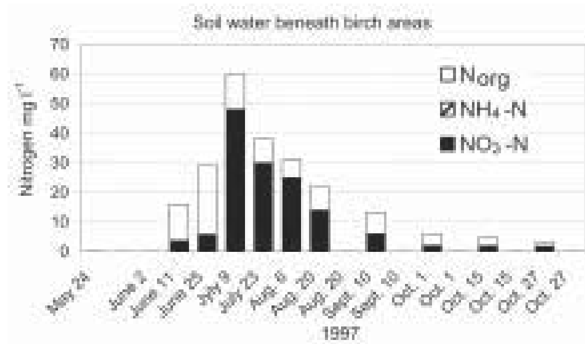

Figure 6. Total nitrogen concentration in soil waters beneath birch areas in 1997.

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. The efficiency of N use by birch seedlings (63%) was slightly better than that of pine seedlings (42% to 52%). When spruce seedlings were grown for 2 years in the nursery, the efficiency of N use by first season seedlings (15%) was much lower than that of second-season seedlings (42%). Results for Swedish nurseries are similar (Hannerz and Rosenberg 2001).

The efficiency of N use by birch seedlings fertilized with slow-release fertilizer was lower (29% to 45%) than that of seedlings fertilized partly with liquid fertilizer (66% to 81%). 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. However, the differences between fertilization systems were no longer so clear when the amounts of N fertigated outside the seedlings were included in the efficiency calculations. The efficiency of N use of fertigated seedlings dropped to 50% (1998) and to 60% (1997).

When efficiency is examined from the seedling standpoint, we measure how effectively a seedling has used nutrients applied to it. On the other hand, when we look upon efficiency from the production standpoint, we calculate how effectively the shipped crop has used applied nutrients. 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.

Determination of seedling nutrient content could be one means to develop fertilizer efficiency. However, with nutrient content of seedlings or the crop, only the potential risk of nutrient leaching can be estimated. On the basis of leaching studies, only a part of the amount of N and P, which the seedlings did not take up from applied N and P, leached from container medium.

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. Propiconazole was an exception; almost 30% of applied amounts leached from Plantek containers in 1997.

The different water solubility of propiconazole and chlorothalonil, 100 and 0.9 mg/l (Tomlin 1997), respectively, could be a reason for the differences in amounts leached. Bruhn and Fry (1982) have shown that rainfall removed cholorothalonil from 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.

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, but the mean weekly concentrations in leachates were usually less than 100 μg/l. The fluctuation was typical for the concentrations; concentrations were usually highest after application and decreased before a new application. Repeated applications did not increase pesticide concentrations in the leachates. During 1997 to 1998, chlorothalonil was analyzed from 18 soil water samples. The chlorothalonil concentration of 4 samples exceeded the limit of detection, 0.1µg/l in 1998. The highest measured value was 2.4 µg/l.

In addition to processes on needles and shoots, the processes in peat medium are obvious causes of the small amounts of pesticides leached. Because triadimenol, the degradation product of triadimefon, was the only degradation product measured, it is impossible to know whether the reason for the small amount of leaching was adsorption of pesticides to peat and/or pesticide degradation to their metabolites.

Summary

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, 2 aspects connected with production of tree seedlings in containers may increase the risk: the same type of production continuing at the same place for years and most of the annual nutrient leaching occurring during 1 or 2 months. If a nursery locates near surface water bodies, P and pesticides toxic to aquatic animals in runoff water could also be a risk.

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 the use of mobile boom sprayers instead of sprinklers, and improving the lay-out of irrigation systems and/or container trays.

The use of slow-release fertilizer could be one solution. However, this option includes uncertainties. Obviously, to get the desired growth of seedlings, large amounts of fertilizers have to be used in Finnish growing conditions. 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. Indeed, the slow-release fertilizers include a large group of products with different properties, which means that the results concerning a product might not be valid for other products.

The seedling canopy and the peat medium in containers effectively adsorbed the pesticides studied when seedlings were grown in containers. The container type and the active ingredient, however, influenced the amounts of active ingredient leached through containers. More studies with different pesticides used on 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.

In Finland, about half of the herbicides were used in areas without seedlings. Weed control in all adjacent areas is important because they 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, possibly due to the low organic matter content of the soil. Although the nurseries already use 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.

References

Addiscott TM, Whitmore AP, Powlson DS. 1991. Farming, fertilizers and the nitrate problem. Wallingford: CAB International. 170 p.

Bruhn JA, Fry WE. 1982. A mathematical model of the spatial and temporal dynamics of chlorothalonil residues on potato foliage. Phytopathology 72:1306-1312.

Colangelo DJ, Brand MH. 2001. Nitrate leaching beneath a containerized crop receiving trickle or overhead irrigation. Journal of Environmental Quality 30:1564-1574.

Dumroese RK, Wenny DL, Page-Dumroese DS. 1995. Nursery waste water: the problem and possible remedies. In: Landis TD, Cregg B, technical coordinators. National Proceedings: Forest and Conservation Nursery Associations - 1995. Portland (OR): USDA Forest Service, Pacific Northwest Research Station. General Technical Report PNW-GTR-365. p 89-97.

European Community. 1998. Council Directive 98/83/EC on the quality of water intended for human consumption. Official Journal of the European Communities L330:32-54.

Gallivan GJ, Surgeoner GA, Kovach J. 2001. Pesticide risk reduction on crops in the province of Ontario. Journal of Environmental Quality 30:798-813.

Hannerz M, Rosenberg O. 2001. Näringsutnyttjande och läckage vid praktisk plantodling. SkogForsk, Arbetsrapport nr 480. 23 p.

Hannerz M, Nyström C. 2002. Kemiska bekämpningsmedel i svenska skogsplantskoler. SkogForsk, Arbetsrapport nr 493. 18 p.

Heiskanen J. 1993. Favourable water and aeration conditions for growth media used in containerized tree seedling production: a review. Scandinavian Journal of Forest Research 8:337-358.

Heiskanen J. 1995. Irrigation regime affects water and aeration conditions in peat growth medium and the growth of containerized Scots pine seedlings. New Forests 9:181-195.

Juntunen M-L. 2000. Weeds, diseases, insects and mites and use of pesticides in Finnish forest nurseries–results of survey study. In: Lilja A, Sutherland J, editors. Proceedings of the 4th Meeting of IUFRO Working Party 7.03.04–Diseases and Insects in Forest Nurseries. The Finish Forest Research Institute. Research Papers 781. p 17-32.

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

Juntunen M-L. 2002. Environmental impact of fertilizers and pesticides used in Finnish forest nurseries. The Finnish Forest Research Institute. Research Papers 849. 58 p.

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

Juntunen M-L, Kitunen V. 2003. Leaching of propiconazole and chlorothalonil during production of *Pinus sylvestris* seedlings in containers. Scandinavian Journal of Forest Research 18(1):45-53.

Juntunen M-L, Hammar T, Rikala R. 2003a. Leaching of nitrogen and phosphorus during production of forest seedlings in containers. Journal of Environmental Quality 31:1868-1874.

Juntunen M-L, Hammar T, Rikala R. 2003b. Nitrogen and phosphorus leaching and uptake by container birch seedlings (*Betula pendula* Roth) grown in three different fertilizations. New Forests 25(2):133-147.

Kauppi L, Pietiläinen O-P, Knuuttila S. 1993. Impacts of agricultural nutrient loading on Finnish watercourses. Water Science and Technology 28:461-471.

Lamhamedi M, Lambany G, Margolis H, Renaud M, Veilleux L, Bernier P. 2001. Growth, physiology, and leachate losses in *Picea glauca* seedlings (1+0) grown in air-slit containers under different irrigation regimes. Canadian Journal of Forest Research 31:1968-1980.

Landis TD, Tinus RW, McDonald SE, Barnett JP. 1989. Seedling nutrition and irrigation. Volume 4. The Container Tree Nursery Manual. Washington (DC): USDA Forest Service. Agriculture Handbook 674. 119 p.

Landis TD, Campbell S, Zenzen F. 1991 Agricultural pollution of surface water and groundwater in forest nurseries. In: Landis, TD, technical coordinator. Proceedings, Intermountain Forest Nursery Association; 1991 August 12-16; Park City, UT. Fort Collins (CO): USDA Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report R-211. p 1-15.

Lilja S. 1986. Diseases and pest problems on *Pinus sylvestris* nurseries in Finland. OEPP/EPPO Bulletin 16:561-564.

Lilja A, Lilja S, Kurkela T, Rikala R. 1997. Nursery practices and management of fungal diseases in forest nurseries in Finland. A review. Silva Fennica 31:79-100.

McAvoy RJ, Brand MH, Corbett EG, Bartok Jr JW, Botacchi A. 1992. Effect of leachate fraction on nitrate loading to the soil profile underlying a greenhouse crop. Journal of Environmental Horticulture 10:167-171.

Nyström C, Hannerz M, Stenström E, Lindelöw Å. 2001. Enkätsudersökning om skogsplantskolornas miljöpåverkan. SkogForsk, Arbetsrapport 484. 13 p.

Puustjärvi V. 1977. Peat and its use in horticulture. Turveteollisuusliitto r.y. Publication 3. Liikekirjapaino, Helsinki. 160 p.

Rekolainen S, Posch M, Turtola E. 1993. Mitigation of agricultural water pollution in Finland: an evaluation of management practices. Water Science and Technology 28:529-538.

Rekolainen S, Ekholm P, Ulen B, Gustafson A. 1997. Phosphorus losses from agriculture to surface waters in the Nordic countries. In: Tunney H, Carton, OT, Brookes PC, Johnston AE, editors. Phosphorus loss from soil to water. CAB International. p 77-93.

Tiessen H (editor). 1996. SCOPE 54 – Phosphorus in the global environment – transfers, cycles and management. Scientific Committee On Problems of the Environment (Scope URL: http://www.iscu-scope.org). 480 p.

Tomlin C, editor. 1997. The Pesticide Manual. Eleventh edition. British Crop Protection Council and the Royal Society of Chemistry. 1606 p. ISBN 1-901396-11-8.

US EPA. 2001. National primary drinking water standards. Office of Water. EPA 816-F-01-007. (URL: http://www.epa.gov./safewater)

Vitousek PM, Aber JD, Howarth RW, Likens GE, Matson PA, Schindler DW, Schlesinger WH, Tilman DG. 1997. Human alteration of global nitrogen cycle: sources and consequences. Ecological Applications 7:737-750.