

Composting of Forest Nursery Waste and Nutrient Leaching

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Abstract

The properties of forest nursery waste from the viewpoint of composting are not well known. The objective of the study was to clarify the properties of the forest nursery waste in order to get the thermophilic composting process going on. The composting process and nutrient leaching during composting was also studied. Forest nursery waste including tree seedlings and their growing media (*Sphagnum* peat), weeds, fallen leaves and grass clippings was composted in 300-litre experimental bins for three months. In the first summer, forest nursery waste was composted with and without horse manure, and during the second summer with and without urea or methylene urea fertilizer. Temperature, volume reduction, pH, water and the organic matter content, nutrient concentrations, water percolation and nutrient leaching were monitored during the composting. Horse manure was the only additive material, which ensured the thermophilic composting process. All additives increased the nitrogen leaching, and horse manure also increased the phosphorus leaching. The results suggest that additive material, such as horse manure, is needed to improve the heating process in forest nursery waste composting. However, the nutrient rich additive material may pose risk for the environment.

Key words composting, forest nursery waste, horse manure, nutrient leaching, methylene urea, nitrogen, organic matter, phosphorus, potassium, thermophilic process, urea

Introduction

Approximately 150 million forest seedlings are delivered for planting annually in Finland. About 90 % of the forest seedlings are produced by seven nursery companies that own a total of 24 nurseries. The remaining 10 % of the produced seedlings are grown in small, family-owned forest nurseries, comprising a total of 60 to 70 nurseries. Nowadays, about 90 % of the production is container seedlings, although bare-root seedlings are also still produced (Poteri 2003).

If seedlings are affected by plant diseases or pests, or they do not meet the size and shape requirements, then they should be culled off before selling (Rikala 2000). Thus forest nursery biowaste includes e.g. culled coniferous and deciduous tree seedlings and their growth media (*Sphagnum* peat), weeds, grass clippings and fallen leaves. The annual amount of biowaste produced in Finnish forest nurseries varies, but the average amount per forest nursery is about 50 m³ (Veijalainen *et al.* 1999).

According to a questionnaire (Juntunen and Rikala 2001), forest nurseries find the handling of biowaste problematic (unpublished data). The Finnish Waste Act (1072/1993) does not allow the heaping up or burning of biowaste in an uncontrolled fashion in the forest nursery fields. Disposal of biowaste by land-

filling is not a solution, because the number of landfills is decreasing and the regulations governing the use of landfills have been tightened (European Communities 1999). Moreover, from the environmental point of view, it is not a good policy to transport biodegradable material from one site to another. Owing to the increasing political and economical pressures on minimising the generation of waste, there is a need to study composting as one solution to recycle the organic, rejected material produced in forest nurseries to a reusable material.

Composting is one of the oldest solid waste treatment methods, and the principles of the composting process are well known (Gray *et al.* 1971a, Poincelot 1974, Crawford 1983, Haug 1993). The composition of the waste material affects the composting process, and optimization of the process parameters has to be specific to the type of waste material to be treated in order to get the temperature rise high enough to kill weeds seeds and plant pathogens (Haug 1993, Grundy *et al.* 1998). As the composting of organic waste produced by forest nurseries has been a relatively neglected subject, it is necessary to investigate it in more detail.

Since the Finnish forest nurseries are of small size and have limited resources to carry out composting, the composting method should be cheap and easy to

implement technically without negative environmental impacts. Composting can also represent a local risk of environmental contamination by nutrients, pesticides and other harmful substances because some of the forest nurseries are located on groundwater aquifers and/or near lakes and rivers (Jaakkonen and Sorvari 2006). Concern about the eutrophication of watercourses or surface waters and the quality of groundwater is worldwide. As a result, the leaching of nitrogen and phosphorus from manure compost has been studied in many countries (Martins and Dewes 1992, Ulén 1993, Parkinson *et al.* 2004). However, there is no information available about forest nursery waste composting and nutrient leaching.

The aim of our study was to clarify the composting of the forest nursery waste. The main objective was to ensure the thermophilic composting process and show the possible nutrient leaching during composting. Small-scale composting experiments, reported here, were done in addition to large-scale windrow composting (Veijalainen *et al.* 2007) in order to produce the best management practices for the handling of forest nursery waste on-site in the forest nurseries. In the first summer, forest nursery waste was composted in bins with and without cutter chip bedded horse manure in order to find out if additive material, such as horse manure, needed to get the thermophilic composting process going on. During the second summer, the study focused on the question of whether it is possible to replace manure with urea or methylene urea fertilizer, both of which are easier to handle than horse manure.

Materials and methods

Preparation of the composts

The experiment was carried out in two parts during the summers of 1999 and 2000. In both years, the compost material consisted of typical forest nursery waste, such as tree seedlings birch (*Betula pendula* Roth), Norway spruce (*Picea abies* (L.) Karst.), Scots pine (*Pinus sylvestris* L.) and their growing media (low-humified *Sphagnum* peat), weeds and grass clippings. In the first summer (1999) the forest nursery waste was composted unchopped without additive material in W1 bins (n=4), and chopped with cutter chip bedded horse manure (one-third of total volume) in HM1 bins (n=4). Horse manure was chosen as an additive material, because it is drier, and thus, manageable when compared to manure from cattle and pigs. During the second summer (2000), forest nursery waste composted with 420 g of urea (Kemira Corp., Finland) in U2 bins (n=4), with 450 g of slow-release methylene urea (Kemira Corp., Finland) in MU2 bins (n=4) and

chopped without additive material in the W2 bins (n=4).

Composting was performed in wooden, heat-insulated 300 litre bins (60 cm high, 70 cm deep and 70 cm wide). The sidewalls of each bin were insulated with 6 cm thick styrofoam sheets. The bottom of the bins were raised above the ground and consisted of galvanized netting to keep the composts well aerated. The bins were placed uncovered in two rows on an open field. All the treatments had four replicates and the location of the treatments was randomized. In both years, the waste material was piled in the bins after the middle of June, and water was added to the bins to give a water content of 50–70 mass-% (Gray *et al.* 1971b). In order to raise the temperature of the W1 composts, weed residues were added to the bins and the content of the bins was turned over after four weeks of composting. The composting process (temperature, volume reduction, pH, water and the organic matter content and nutrient concentrations), water percolation and nutrient leaching were monitored during the 12 weeks' composting period.

Physical and chemical analyses

The temperature in the compost material in the central part of the composts was measured three times a week for the first month, and after that once a week. Volume reduction of the composting material was monitored weekly by measuring the height of the piles. Five subsamples (200 g composite sample) were collected weekly from each compost. The samples were pre-treated (ISO 11464 1994) and the pH was measured on a pH meter (model 3020, Jenway, England) at a ratio of 5:1 distilled water to material (vol/vol) (ISO 10390 1994). The water content was determined by gravimetric analysis (ISO 11465 1993). Organic matter (OM) was determined by loss of mass on ignition of oven-dried samples at 550 °C to constant mass. Carbon (C) and nitrogen (N) concentrations in the compost materials were determined on a LECO CHN-600 analyzer (Leco Co, St Joseph USA). The phosphorus (P) and potassium (K) concentrations were determined, following dry digestion (550 °C, extraction of the ash with 2 M HCl) (Halonen *et al.* 1983), by inductively coupled plasma atomic emission spectrophotometry (ICP/AES, ARL 3800). The C, N, P and K concentrations were determined at the beginning and end of the composting period.

Water percolation and nutrient leaching

The percolation water was collected weekly in 1999 and every second or third week in 2000 (depending on the amount of rainfall). The collection vessels located under each bin were smaller than the bottom

of bins in order to avoid the collection of the water flowing directly down the inner walls of the bins (not percolated through the composting material). The volume of the percolation water was measured after each collection period. The samples were stored frozen and filtered through Schleicher & Schuell 589/2 filter paper before the nutrient analysis. Total soluble N, ammonium ($\text{NH}_4\text{-N}$) and nitrate + nitrite ($\text{NO}_3\text{-N} + \text{NO}_2\text{-N}$) concentrations were analysed by FIA (flow injection analysis) (Tecator 5012, Foss, Sweden and QuikChem 8000, Lachat Instruments, USA). Total P was analysed by inductively coupled plasma atomic emission spectrophotometry (ICP/AES, ARL 3580, Switzerland). The amount of leached N and P (g m^{-2}) was calculated by multiplying the nutrient concentration (g L^{-1}) by the volume of the percolation water (L m^{-2}).

Statistics

The differences in N, P and K concentrations, the OM content, pH (tested as $[\text{H}^+]$), C/N and C/P ratio between the initial composting materials were tested with one-way analysis of variance (SPSS 14.0 for Windows). One-way ANOVA was also used to test the difference in the total volume reduction between composts at the end of the 12 weeks' composting period. For each variable, the homogeneity of variances among composts was tested with Levene's test. In order to equalize variances, values of the OM contents were transformed to square root values, C/N ratios to squared values and P concentrations to reciprocal values before analysis. Means were compared for significant differences at $p < 0.05$ by Tukey's test. The change in N, P and K concentrations, OM content, C/N and C/P ratio within each compost type during the 12 weeks' composting was tested by paired-samples t-test. Multivariate analysis of variance was used to test the differences in time course of temperature between composts, using temperature as a repeated factor. Independent-samples t-test was used to test the differences between weekly mean air temperatures in 1999 and 2000.

Weather conditions

Ambient air temperature and precipitation were recorded at a meteorological station located about 500 m from the composting site. Weekly mean air temperature did not vary considerably between the test years during the 12 weeks' composting. The temperature was different between years only in 4th, 9th and 12th week ($p < 0.05$) (Table 1). Thus we assume that ambient air temperature had no effect on the heating process inside the compost bins. Weekly mean precipitation varied between the years during the 12 weeks' composting (Table 1).

Table 1. Weekly mean air temperatures ($^{\circ}\text{C}$) and precipitation (mm) at experimental site in 1999 and 2000 during the 12 weeks' composting

Week	Temperature, $^{\circ}\text{C}$		Precipitation, mm	
	1999	2000	1999	2000
1 st	21	19	7.0	0.2
2 nd	19	20	31.8	67.2
3 rd	17	16	12.2	12.9
4 th	21 *	17 *	26.3	4.6
5 th	18	18	31.4	57.3
6 th	14	15	2.8	6.0
7 th	15	15	3.1	40.1
8 th	13	13	2.6	22.3
9 th	12 *	14 *	5.4	15.3
10 th	13	13	14.0	11.9
11 th	15	14	1.0	8.4
12 th	13 *	8 *	8.4	8.2

* Mean weekly temperatures are significantly different ($p < 0.05$) between years. Independent-samples t-test.

Results

Composting process

The difference in time course of temperature was significant between composts ($p < 0.001$). In the HM1 composts, composting reached the thermophilic phase ($> 40^{\circ}\text{C}$) rapidly in two days, with temperatures of as high as $67 \pm 1^{\circ}\text{C}$ for two days, followed by temperatures above 40°C for 1.5 weeks (Figure 1). The temperature was over 40°C (maximum 42°C) for three days in the U2 composts (Figure 1). However, the temperature did not rise above 40°C in W1, W2 and MU2 composts, although nitrogen-rich weeds were added and the material was turned over in W1 composts after four weeks' composting.

The volume of the composting material decreased rapidly during the first week (Figure 2a). During the whole composting period, the greatest loss occurred in the HM1 composts ($31 \pm 2\%$) due to the most inten-

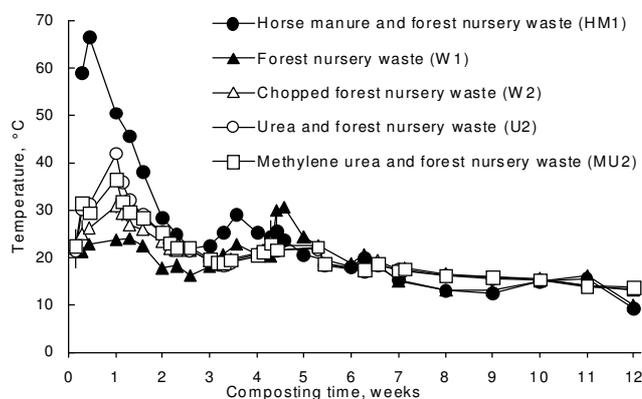


Figure 1. Time course of temperature ($^{\circ}\text{C}$) inside the composts during the 12 weeks' composting. Bars indicate standard deviations

sive decomposition ($p < 0.05$). The loss was the smallest in the W1 composts ($18 \pm 1\%$), where forest nursery waste was not chopped. Chopping of the waste material increased the volume reduction, which can be seen in comparison between W1 and W2 composts ($p < 0.05$) (Figure 2a).

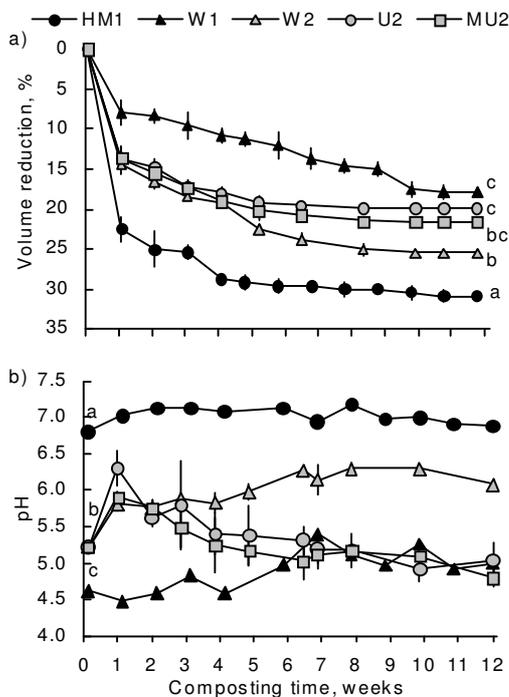


Figure 2. Volume reduction (% of initial) (a) and pH (b) of the composting materials during the 12 weeks' composting. Bars indicate standard deviations. Different letters (a, b, c) denote significant differences ($p < 0.05$) in the final volume reduction (Figure 2a) and in the initial pH (Figure 2b) between composts. ANOVA and Tukey's test. For compost codes, see Figure 1

The addition of horse manure increased the pH of the initial composting material ($p < 0.05$) (Figure 2b). The pH remained neutral (6.8 – 7.2) in HM1 composts during the 12 weeks' composting. The composting materials in all the other composts remained acidic (4.5 – 6.3) during the 12 weeks' composting (Figure 2b). The mean water content was 50 – 68 mass-% in all bins during the 12 weeks' composting. The OM content was initially higher in HM1 and W1 composts than in W2, U2 and MU2 composts ($p < 0.05$) (Table 2). The OM content decreased in all composts during the 12 weeks' composting, although the decrease was not significant in any compost (Table 2).

At the beginning of the process, the C/N ratio was below 40:1 in all other composts, except W1 (Table 2). The decrease in the C/N ratio was relatively small during 12 weeks' composting, although it was significant

Table 2. Organic matter content (OM, % of DM), C/N ratio and C/P ratio in composting materials: HM1 = horse manure and chopped forest nursery waste, W1 = no chopped forest nursery waste, W2 = chopped forest nursery waste, U2 = urea and chopped forest nursery waste, MU2 = methylene urea and chopped forest nursery waste before and after 12 weeks' composting. Mean of four replicates \pm standard deviation

Compost code	OM content, %		C/N ratio		C/P ratio	
	before	after	before	after	before	after
HM1	62 \pm 3 (a)	54 \pm 5	34 \pm 3 (b)	28 \pm 5	210 \pm 30 (b)	225 \pm 30
W1	72 \pm 14 (a)	59 \pm 7	42 \pm 3 (a)	36 \pm 1	660 \pm 20 (a)	450 \pm 135
W2	31 \pm 1 (b)	25 \pm 5	35 \pm 1 (b)	30 \pm 1	250 \pm 30 (b)	280 \pm 100
U2	31 \pm 1 (b)	26 \pm 5	22 \pm 1 (c)*	22 \pm 1	250 \pm 30 (b)	235 \pm 50
MU2	31 \pm 1 (b)	29 \pm 5	22 \pm 1 (c)*	20 \pm 4	250 \pm 30 (b)	310 \pm 50

* Theoretical value calculated on the basis of the amount of added nitrogen and original N concentration in the forest nursery waste (W2). Data followed by different letters (a, b, c) denote significant differences ($p < 0.05$) between initial composting materials. ANOVA and Tukey's test.

in W1 and W2 compost. The initial C/P ratio was = 250 in all other compost, except W1, and thus favourable for microbial growth (Table 2). C/P ratio did not change significantly in any compost during the 12 weeks' composting (Table 2). The initial N concentration was higher in HM1 and W1 composts than in W2, U2 and MU2 composts (Figure 3a). N concentration did not change significantly in any other compost than in MU2 during

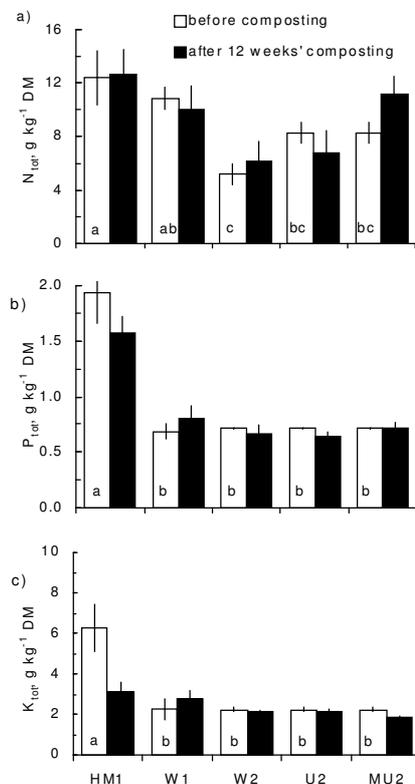


Figure 3. Total nitrogen (N) (a), phosphorus (P) (b) and potassium (K) (c) concentrations (g kg^{-1} of dry matter) before and after 12 weeks' composting. Bars indicate standard deviations. Different letters (a, b, c) inside columns denote significant differences ($p < 0.05$) in the initial nutrient concentrations between composts. ANOVA and Tukey's test. For compost codes, see Figure 1

the 12 weeks' composting (Figure 3a). The addition of horse manure increased significantly the initial P and K concentration of the composting material (Figure 3b). The initial and final P concentration was higher in the HM1 composts than that in all the other composts ($p < 0.05$) (Figure 3b). The K concentration decreased significantly only in HM1 composts during the 12 weeks' composting (Figure 3c).

Water percolation and nutrient leaching

Water percolation was generally small. The amount of percolation water was 16 – 76 L m⁻² from all composts during 12 weeks' composting, being 11 – 38 % of the precipitation during the experiments (Figure 5a). A decrease in the ammonium concentration, together with an increase in the nitrate concentration, was detected in the percolation water during the composting (Figures 4a & b). In the HM1 composts, the concentration of ammonium in the percolation water was highest (190 mg L⁻¹) during the thermophilic phase of the composting process (Figure 4a). As composting proceeded, the ammonium concentration decreased as a result of nitrification in HM1 composts. In U2 bins, the ammonium concentration was high (270-390 mg L⁻¹) in the percolation water during the whole 12 weeks'

composting period (Figure 4a). However, nitrate occurred at the later stages of the process as a result of nitrification also in the U2 composts (Figure 4b). In the MU2 composts, ammonium concentration increased later than in the U2 composts, being the highest (360 mg L⁻¹) after 4 weeks' composting. The increase in nitrate concentration also occurred in the MU00 composts (Figure 4b). The concentrations of ammonium and nitrate were low in the percolation water of W1 and W2 composts where pure forest nursery waste was composted (Figures 4a & b).

Irrespective of the form in which the nitrogen was added, all the additive materials (horse manure, urea and methylene urea) increased the amount of leached N (Figure 5b). The total amount of leached N was the highest (54 g m⁻²) in the U2 composts, being slightly higher than in the MU2 and HM1 composts (34 g m⁻² and 27 g m⁻², respectively). The total amount of leached

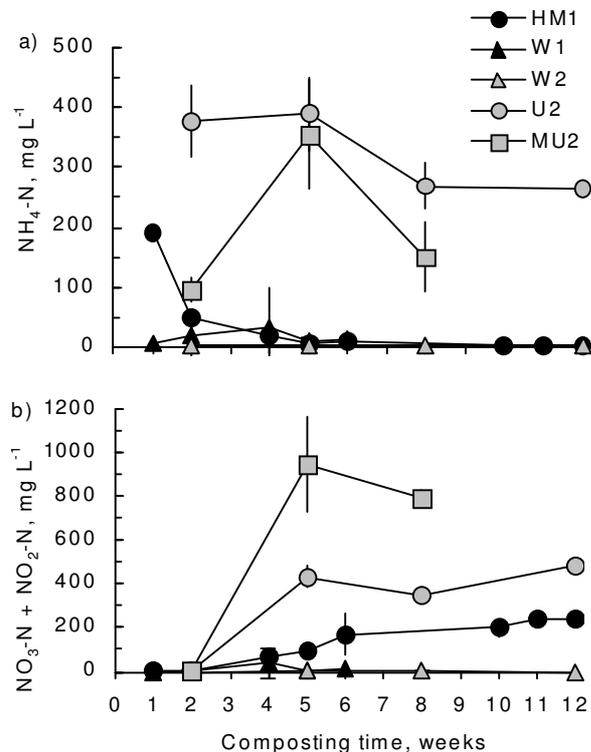


Figure 4. Ammonium (NH₄-N) (a) and nitrate + nitrite (NO₃-N + NO₂-N) (b) concentrations (mg L⁻¹) in percolation water during 12 weeks' composting. Bars indicate standard deviations. For compost codes, see Figure 1

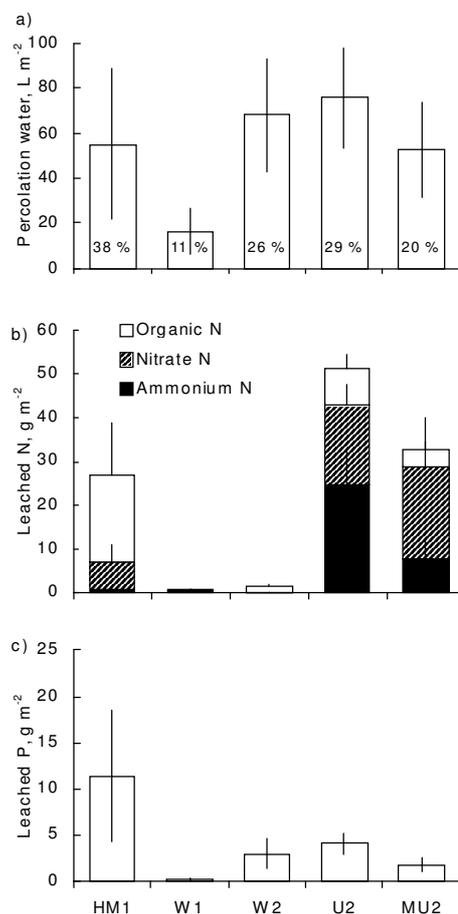


Figure 5. Total amount of percolation water (L m⁻²) and the amount of water (%) of the precipitation (a), leached nitrogen (N, g m⁻²) (b) and phosphorus (P, g m⁻²) during the 12 weeks' composting. Bars indicate standard deviations. For compost codes, see Figure 1

N was low in the W1 and W2 composts (less than 2 g m⁻²) where forest nursery waste was piled without additive material. The half of the leached N was in the form of NH₄-N in the U2 and W1 composts (Figure 5b). A total of 74 and 85 % of the leached N was organic in the HM1 and W2 composts, respectively. The proportion of NO₃-N was highest (65 %) in the MU2 composts. The highest initial P concentration of the material in the HM1 composts (Figure 3b) also resulted in the highest total amount of leached P (11 g m⁻²) (Figure 5c).

Discussion and conclusions

The thermophilic phase was reached only in composts with forest nursery waste and horse manure (HM1). The generation of sufficient heat in the composts is essential for the eradication of plant pathogens and weed seeds commonly found in many types of composts (Hoitink *et al.* 1976, Yuen and Raabe 1984, Eghball and Lesoing 2000). In our HM1 composts, as well as in other experiments (Paré *et al.* 1998, Eiland *et al.* 2001, Veijalainen *et al.* 2007), manure acted as the source of nutrients (N, P and K) that enable effective growth of the microbes responsible for OM decomposition and consequent rise in temperature. In addition, manure acted as a source of easily available C compounds and an inoculum of microbes that made the process more effective (Rynk 1992, Carisse *et al.* 2003, Raviv 2005).

According to Golouke (1991), the initial C/N ratios were theoretically suitable (25-40:1) for microbial activity in all the composts, except W1 composts. Despite this, the composting process in our study did not reach the thermophilic stage in most of the composts. The failure of the thermophilic process was probably the combination of several factors, such as lack of nutrients and easily available C, the low initial OM content and low pH (Haug 1993). Neither urea nor methylene urea contained any P or K, which are also important nutrients for multiplying microbes (Gray *et al.* 1971b). In this respect, ammonium phosphate had probably been a better admixture than urea or methylene urea because it contains both N and P (Haug 1993).

The decomposition of waste material begins with the metabolism of easily available C compounds in the presence of nutrients, leading to the initial heat production and thermophilic phase (Gray *et al.* 1971a, Haug 1993). In all other composts, except HM1, organic material was pure forest nursery waste, e.g. tree seedlings, in which the carbon is mainly in the form of cellulose, hemicellulose and lignin (Kaakinen *et al.* 2004). Cellulose is relative resistant to biodegradation especially when it is associated with hemicellulose and

lignin as lignocellulose, and thus it requires a relatively long composting time (Eriksson *et al.* 1990, Haug 1993). Thus the decrease in the C/N ratio in all the composting materials was relatively small during the 12 weeks' composting. Same phenomenon was noticed by Benito *et al.* (2003) in the composting of pruning wastes.

The low initial OM content (31 %) and consequently low C content in the waste material composted in 2000 was also responsible for the failure of the thermophilic composting process in these composts. On the other hand the thermophilic temperature was not reached in the large-scale forest nursery waste windrows with urea addition, although the OM content was 47 % at the beginning of the composting (Veijalainen *et al.* 2007). In our study, the low initial OM content was caused by the high amount of inorganic material e.g. sand in the forest nursery waste. The sand was stuck on the birch seedlings, which were kept in the sand bed during the winter. Also the roots of the weeds and bare-root seedlings, which were removed from sandy fields, brought inorganic material to the process. According to our study, the quality of the forest nursery waste material is heterogeneous, which makes the composting of forest nursery waste more complicated than expected.

The greatest loss in the volume of composting material occurred in the HM1 composts as a result of the intensive microbial decomposition (Inbar *et al.* 1993). The particle size reduction had probably positive effect on the composting process in HM1 composts by increasing the surface area of waste material (Crawford 1983, Haug 1993). However, composting material was only loosely compressed in the bins at the beginning of our experiment, and thus the volume reduction may be partly due to the increasing density of the material, *i.e.* mechanical compaction, as reported by Churchill *et al.* (1995).

Bacterial decomposers prefer a pH range of 6.0-7.5 and fungal decomposers 5.5-8.0 (Golouke 1991). Moreover, the thermophilic phase of composting is dominated by bacteria, which are generally not acid tolerant (Atlas and Bartha 1998). In our study, only horse manure neutralized the acidity in the composts and made forest nursery waste more suitable for microbial decomposition in the HM1 composts, as was also noticed in the windrow composting of forest nursery waste (Veijalainen *et al.* 2007). The composting materials in all the other bins remained too acidic probably mostly because of the high proportion of *Sphagnum* peat, which is acidic due to the presence of weak organic acids, particularly fulvic acids (Puuustjärvi 1991). Thus pH adjustment e.g. with lime would be desirable if the material is both acidic and has a

low N content, e.g. forest nursery waste (Haug 1993). The water content was within the optimum range (50 – 70 %) in all composting material during the 12 weeks' composting (Gray *et al.* 1971b).

The changes in the nitrogen forms of the percolation water indicate the stage of the composting process (Martins and Dewes 1992, Parkinson *et al.* 2004). At the beginning of the composting the increase in the $\text{NH}_4\text{-N}$ concentration, due to the ammonification reactions resulting from the microbial activity, was clear in the percolation water of HM1 composts. However, high $\text{NH}_4\text{-N}$ concentration in the percolation water of U2 composts was probably due to the hydrolysis of the urea into $\text{NH}_4\text{-N}$. In the MU2 composts, $\text{NH}_4\text{-N}$ concentration increased later than in the U2 composts, presumably due to the slower dissolution and hydrolysis of this form of urea. Despite this, the nitrogen from these sources was available more quickly than the carbon in the forest nursery waste, and thus the nitrogen compounds occurred in the percolation water of these composts (Rynk 1992). Gaseous losses of ammonia have hardly occurred in this study, because the volatilization of $\text{NH}_3\text{-N}$ is not liable at acid or near neutral pH (Golouke 1991). As the composting proceeded, nitrification, *i.e.* the conversion of $\text{NH}_4\text{-N}$ into $\text{NO}_3\text{-N}$ was detected, when the temperature of the compost was below 40°C and the conditions aerobic, as has also been observed by Sánchez-Monedero *et al.* (2001) and Parkinson *et al.* (2004). The low concentrations of $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ in the W1 and W2 composts indicate that there is a lack of available nitrogen for effective microbial activity in the pure forest nursery waste.

The total amounts of the leached nutrients were ten times higher from the small units used in this study than from the large-scale windrows reported by Veijalainen *et al.* (2007). Thus there is no reason to make broader conclusions about the leaching results from this study as a direct measure of environmental contamination. According to our studies, caution should be used when the results of small-scale composting experiments are generalized to the prevalent usage. However, the comparison between the chemical compositions of the percolation water from the different composts is valid in this study. In this respect, the additional nutrient and microbial sources needed for effective composting might pose a risk to the environment if the compost is placed at the same site for a long time and water percolation is not prevented or the percolation water is not collected.

In conclusions, the waste material produced in forest nurseries is not ideal for composting. The quality of waste material is variable and the amount of mineral material may be unexpectedly large. Accord-

ing to our results, nutrient amendment seems to be necessary for reaching the thermophilic temperatures during composting of forest nursery waste. Horse manure was advantageous as a source of nutrients and neutralizing compounds that enable effective growth of the microbes responsible for OM decomposition and consequent rise in temperature. Urea and methylene urea did not promote the rise in temperature in an expected manner. Artificial fertilizers bring nitrogen to the process but they lack the other beneficial features typical of organic additives, e.g. horse manure. The composting process should be long-term than the monitoring period used in this study to enable the decomposition of slowly degradable woody tree seedlings. Chopping raw material and turning could be the ways to accelerate the process and to guarantee a uniform quality of the compost product. All additive materials increased the nitrogen leaching, and horse manure also increased the phosphorus leaching.

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КОМПОСТИРОВАНИЕ ОТХОДОВ В ЛЕСНЫХ ПИТОМНИКАХ И ВЫЩЕЛАЧИВАНИЕ УДОБРЕНИЙ

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Резюме

Свойства отходов в лесных питомниках, с точки зрения их разложения, ещё окончательно не изучены. Целью этой работы является установить свойства отходов лесных питомников для ускорения термофильного процесса разложения отходов. Также изучался процесс компостирования и выщелачивание удобрений. Отходы лесных питомников, в составе которых входили сеянцы и субстрат их выращивания (сфагновый торф), сорняки, листья и трава были компостированы в течение трёх месяцев в ящиках объёмом 300 литров. Во время первого вегетационного периода отходы лесных питомников компостировались с лошадиным навозом и без него, а во время второго - с мочевиной или метилен-мочевинной и без внесения удобрений. Температура, уменьшение объёма, кислотность, количество воды и органических веществ, концентрации удобрений, просачиваемость воды и выщелачивание удобрений измерялись во время компостирования. Лошадиный навоз являлся единственным веществом, способствующим термофильному процессу компостирования. Все прибавки способствуют выщелачиванию азота, а лошадиный навоз также увеличил выщелачивание фосфора. Полученные результаты показывают, что прибавки, такие как лошадиный навоз, необходимы для увеличения температуры во время компостирования отходов лесных питомников. Однако, богатые удобрениями прибавки могут создавать угрозу окружающей среде.

Ключевые слова: компостирование, отходы лесных питомников, лошадиный навоз, выщелачивание удобрений, метилен-мочевина, азот, органическое вещество, фосфор, калий, термофильный процесс, мочевиной.