Effects of Nitrogen Fertilization on the Humus Layer and Ground Vegetation under Closed Canopy in Boreal Coniferous Stands

Raisa Mäkipää

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Forest ecosystems may accumulate large amounts of nitrogen in the biomass and in the soil organic matter. However, there is increasing concern that deposition of inorganic nitrogen compounds from the atmosphere will lead to nitrogen saturation; excess nitrogen input does not increase production. The aim of this study was to determine the long-term changes caused by nitrogen input on accumulation of nitrogen in forest soils and in ground vegetation.

The fertilization experiments used in this study were established during 1958–1962. They were situated on 36- to 63-year old Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* (L.) Karsten) stands of different levels of fertility. The experiments received nitrogen fertilization 5–7 times over a 30-year period, and the total input of nitrogen was 596–926 kg/ha.

Nitrogen input increased the amount of organic matter in the humus layer and the nitrogen concentration in the organic matter. Furthermore, the total amounts of nutrients (N, P, K, Ca and Mg) bound by the humus layer increased due to the increase in the amount of organic matter. However, nitrogen input decreased the biomass of ground vegetation. The nitrogen concentration of the plant material on the nitrogen-fertilized plots was higher than that on the control plots, but the amount of nutrients bound by ground vegetation decreased owing to the drastic decrease in the biomass of mosses. Ground vegetation does not have the potential to accumulate nitrogen, because vegetation is dominated by slow-growing mosses and dwarf shrubs, which do not benefit from nitrogen input.

Keywords nitrogen saturation, ground vegetation, nitrogen deposition, forest soils, mosses, dwarf shrubs.

Author's address University of Joensuu, Faculty of Forestry, P.O. Box 111, FIN-80101 Joensuu, Finland.

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1 Introduction

Deposition of inorganic nitrogen compounds from the atmosphere has increased during the latest few decades. The main sources of nitrogen deposition are emissions of NO$_x$ from combustion processes and emission of NH$_3$ from agricultural activities. The nitrogen deposition on the southern coast of Finland is about 10 kg N ha^{-1} a^{-1} and in northern Finland, about 3 kg N ha^{-1} a^{-1} (Järvinen and Vänni 1990).

In boreal forests nitrogen availability is a growth-limiting factor (e.g. Aaltonen 1926). Although forest soils usually contain large amounts of organically bound nitrogen, the slow rate of decomposition caused by the cool humid climate means that nitrogen cycling is slow. Thus input and turnover of nitrogen are very important factors controlling the production and species abundances of forest ecosystems.

Forests may accumulate large amounts of nitrogen in the biomass of the plant and the organic matter of the soil. However, there is increasing concern that deposition of inorganic nitrogen compounds from the atmosphere is damaging the forest ecosystem, i.e. that the forest ecosystem may become nitrogen saturated (Nihlgård 1985, Nilsson and Grennfelt 1988, Ågren and Bosatta 1988, Gundersen 1989). The ecosystem is said to be nitrogen saturated if the availability of inorganic nitrogen exceeds the demand of the organisms (Aber et al. 1989), if nitrogen loss exceeds nitrogen input (Ågren and Bosatta 1988), or if primary production will not be further increased by an increase in nitrogen supply (Nilsson 1986). In the present work the accumulation of nitrogen in humus layer and the production of the ground vegetation are studied under conditions of high nitrogen supply. The ability of the ground vegetation to tolerate long-term nitrogen application are estimated.

There are no long-term experiments in which the effects of atmospheric nitrogen deposition have been investigated, but the effects of nitrogen deposition can be estimated on the basis of long-term fertilization experiments (Tamm 1991). Fertilization by nitrogen cannot be directly compared with nitrogen inputs via deposition (Skeffington and Wilson 1988). Fertilizers are applied in large doses, which differ from deposition, and high nutrient concentrations after fertilization may be more deleterious than the long-term effects of nitrogen supply. On the other hand, nitrogen deposition through the canopy is not included in fertilization experiments. However, fertilization experiments provide empirical data about changes in the nitrogen balance of forest ecosystems as a result of nitrogen input (Mälkönen et al. 1990).

The effects of fertilization on timber production and the nutrient content of trees have been widely studied, and it is known that addition of nitrogen increases the nitrogen concentration in needles and the biomass production of trees (e.g., Gustavsen and Lipas 1975, Kukkola and Saramäki 1983, Mälkönen and Kukkola 1991). Furthermore, Mälkönen (1990) and Mälkönen et al. (1990) reported that addition of nitrogen increased the quantity of organic matter in the humus layer, but did not have any detrimental effects on pH or the amounts of base cations in the humus layer. On the basis of fertilization experiments it is estimated that forest ecosystems are able to accumulate high nitrogen inputs from atmospheric deposition by increased growth of the trees and increased amount of organic matter in the humus layer.

In boreal forests the ground vegetation forms a significant portion of the biomass, particularly in younger stands, and in general plays an important role in the recycling of nutrients. The biomass of ground vegetation and shrubs makes up about 10 % of the total biomass of a young Scots pine stand and as much as 45 % of the annual biomass production (Mälkönen 1974). The importance of ground vegetation in nutrient cycling of boreal forests is due to rapid turnover of biomass and nutrients (34–43 % of aboveground pools annually) relative to that of the trees (2–5 % annually) (Chapin 1983).

Nitrogen fertilization has been found to increase the abundance of herbs and grasses and decrease the abundance of mosses and lichens (Mälkönen et al. 1980, 1982, Persson 1981, Gerhard and Kellner 1986). Tyler (1987), and Falkengren-Grerup (1986, 1989) reported some changes in species composition due to nitrogen deposition and soil acidification. However, the effects of nitrogen input on the biomass and nutrient budgets of ground vegetation are not well known.

The aims of this study were to determine the long-term changes caused by nitrogen inputs on:

- amount of organic matter in the humus layer
- nutrient content of the humus layer
- total biomass of the above-ground parts of ground vegetation
- amounts of nutrients bound by the ground vegetation
- accumulation of nitrogen in forest soils and in the ground vegetation

2 Material and Methods

2.1 Experiments and Fertilization

The nitrogen fertilization experiments used in this study were established during 1958–62 by the Finnish Forest Research Institute. The experiments are located in southern Finland, and they differ from each others with regard to the development stage of the stand and the fertility level of the site (see Table 1 for general information about the stands). Five of the study sites were Scots pine (*Pinus sylvestris* L.) stands, and one was a Norway spruce (*Picea abies* (L.) Karsten) stand. The sizes of the plots were 25 × 25 m^2 or 30 × 30 m^2. In this study differences between control and nitrogen fertilized plots are examined.

The fertilization experiments received nitrogen fertilization 5–7 times over a 26- to 30-year study period (Fig. 1). The fertilizers used were ammonium sulphate in the first nitrogen application, urea in the first refertilization and ammonium nitrate with lime in the most recent fertilizations. Ammonium nitrate with lime contains small amounts of calcium (4.0 %) and magnesium (1.0 %). The nitrogen doses used were increased gradually from 82 N kg/ha to 180 N kg/ha. The total amounts applied were 596–926 kg/ha nitrogen , 48–74 kg/ha calcium and 12–19 kg/ha magnesium.

2.2 Sampling and Analyses

Ten sample quadrates were situated systematically along the fertilized border zone surrounding the experimental plot for sampling soil and ground vegetation. Humus samples were taken with a soil auger (d = 56 mm) from the centre point and corners of each of these quadrates (2 x 2 m), and combined to give one composite sample for chemical analyses. Thus ten samples were analysed per experimental plot. Above-ground parts of the ground vegetation were collected by species (*Vaccinium myrtillus* L., *Vaccinium vitis-idaea* L., *Calluna vulgaris* (L.) Hull, *Linnaea borealis* L. and *Rubus idaeus* L.) or by groups (mosses, lichens, grasses and herbs). The size of the quadrates was 50 × 50 cm for the field layer species and 25 × 25 cm for the bottom layer (mosses and lichens). The vegetation samples were harvested when the field layer biomass was considered to be at its maximum (Vuokko et al. 1977), i.e. from mid-July to the beginning of August.

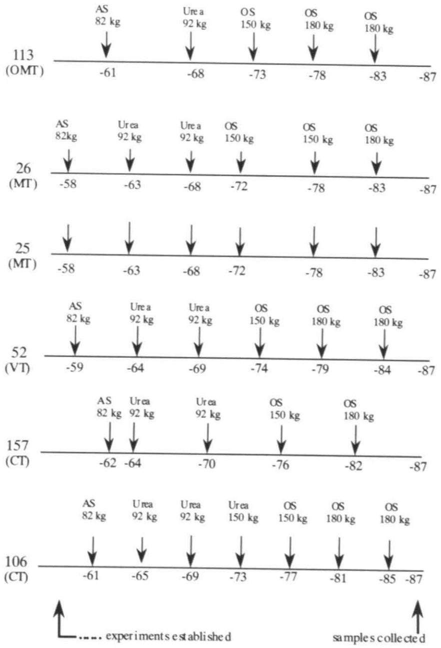

Fig. 1. Fertilizer applications during the study period. The fertilizers used were ammonium sulphate (= AS), urea and ammonium nitrate with lime (= OS). The nitrogen doses used increased from 82 N kg/ha to 180 N kg/ha.

Table 1. Information about the experimental stands at the beginning and end of the experiments. Fertilized plots (=N) received nitrogen fertilization 5–7 times over the 26- to 30-year study period. The total amount of nitrogen applied during the study period was 597–926 kg/ha.

Exp.	Location	Site type	Species	Soil texture class	Site index H_{100}	Treatment (kg/ha)	Beginning Age	Beginning Stem number per ha	Beginning H_{dom} m	Beginning Volume m^3 / ha	End Age	End Stem number per ha	End H_{dom} m	End Volume m^3 / ha	End Humus-layer cm	I_v m^3 / ha / a
113	61°10'N 26°03'E	OMT	spruce	FS M	28	0	12	1792	1.6	0.4	36	1248	17.9	236	1.8	9.1
	(Heinola)					N (684)		1856	1.6	0.3		1296	17.0	239	2.4	9.2
26	61°24'N 25°2'E	MT	pine	FS M	29	0	12	2022	2.4	1	42	1022	17.7	218	4.8	8.3
	(Padasjoki)					N (776)		3289	2.9	1		1156	17.8	256	3.7	10.0
25	61°49'N 29°19'E	MT	pine	FS M	28	0	33	1922	13.2	109	63	765	22.0	254	3.5	7.3
	(Punkaharju)					N (776)		2789	11.9	96		944	22.2	319	4.2	10.0
52	62°1'N 24°48'E	VT	pine	FS S	27	0	9	2857	1.8	0.6	36	1460	15.1	148	1.7	5.3
	(Kuorevesi)					N (776)		2857	1.6	0.4		1044	16.2	197	2.5	7.0
157	61°6'N 26°1'E	CT	pine	FS S	24	0	16	2080	3.8	4	42	1952	14.0	125	0.9	4.7
	(Heinola)					N (597)		2176	4.1	5		1728	14.2	155	2.3	6.0
106	63°23'N 24°17'E	CT	pine	CS S	15	0	25	2467	3.7	2.0	53	2044	10.1	54	3.3	1.9
	(Halsua)					N (926)		2067	3.7	1.7		1867	10.3	77	3.5	2.7

Site types according to the classification of Cajander (1949).
Abbreviations for the soil texture classes are as follows: FS = fine sand 0.02–0.2 mm; CS = coarse sand 0.2–2.0 mm; M = till; S = sorted.
H_{dom} = dominant height,
I_v = Mean volume growth during the course of the experiment.

The plant samples were dried (24 h, 70°C), weighed and milled. Nitrogen was analysed by the Kjeldahl method. Potassium, calcium and magnesium were analysed by an atomic absorption spectrophotometer from ash dissolved in acid (1.0 N HCl), and phosphorus by the molybdate-hydrazine method from the same solution (Halonen et al. 1983).

The humus samples were also dried (24 h, 105°C), weighed and milled. Total nitrogen and carbon were determined in an automatic CHN analyser (LECO). Organic matter content was calculated by multiplying the carbon content by the van Bemmelen factor of 1.72. Other total concentrations of nutrients (P, K, Ca and Mg) were analysed by the same methods as for the plant material. Extractable nutrients (K, Ca and Mg) and soluble phosphorus were extracted by ammonium acetate (pH 4,65) (Halonen et al. 1983).

Statistical significance of the differences between the control and the nitrogen-fertilized plots was tested by the t-test of the SPSS package (SPSS 4.1. VAX/VMS).

3 Results

3.1 Effects of Nitrogen Addition on the Humus Layer

More organic matter was found in the humus layer on the plots fertilized with nitrogen than on those without nitrogen fertilization, except in Experiment 26 (Fig. 2). Experiment 26 was established by sowing after prescribed burning, and the control plot did not burned very well. With the exception of Experiment 26, the amounts of organic matter were 3200 kg/ha (14 %) to 10 550 kg/ha (115 %) higher on the fertilized plots than on the control plots. The humus layer was thicker on the fertilized plots due to accumulation of organic matter during the study period (Table 1).

Nitrogen concentrations of organic matter were higher on the fertilized plots (Table 2). Differences in the other nutrient concentrations (P, K, Ca and Mg) were not evident with respect to total nutrient concentrations of organic matter (Table 2). In rich (Exp. 113) and mesic sites (Exp. 25 and 26), however, the concentration of potassium seemed to decrease due to nitrogen fertilization. There were also differences in the concentrations of the extractable cations calcium and magnesium (Table 3); due to the fertilizer used (ammonium nitrate with lime), the concentrations of these cations were higher on the fertilized plots.

The differences between control and fertilized plots were large with respect to the amount of organic matter in the humus layer, but small in terms of the nutrient concentrations of the humus layer. Therefore the amounts of nutrients bound by the humus layer are controlled mainly by the amount of organic matter in the soil and not by the nutrient concentrations. In most cases the amounts of nutrients (N, P, K, Ca and Mg) in the humus layer were higher on the fertilized plot (Fig. 3). In Experiment 26, however, the amounts of nutrients bound by the humus layer were lower on the fertilized plots due to the smaller amount of organic matter. Furthermore, in Experiment 25 the amount of potassium was lower on the fertilized plot due to the lower concentration of potassium in the humus layer (Fig. 3).

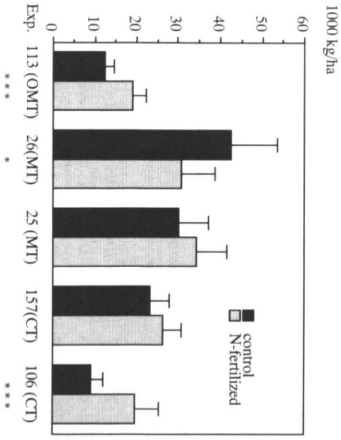

Fig. 2. Amount of organic matter in the humus layer by experiment and treatment.Experiments are situated on different site types; OMT = Oxalis-Myrtillus-type, MT = Myrtillus-type, CT = Calluna-type (based on site type classification of Cajander (1949)). Statistically significant differences are shown by symbols: * = significant ($p < 0.05$); ** = very significant ($p < 0.01$); *** = highly significant ($p < 0.001$).

Table 2. Total nutrient concentrations of the humus layer on the basis of organic matter (0 = control and N = fertilized with nitrogen, $n_0 = n_N = 10$).

Exp.	Treat-ment	N_{tot} g/kg	s.d.	p	P_{tot} g/kg	s.d.	p	K_{tot} g/kg	s.d.	p
113	0	16.5	2.3		2.1	0.7		1.4	0.3	
	N	21.3	1.5	***	2.4	0.6	n.s.	1.3	0.3	n.s.
26	0	14.3	2.2		1.1	0.4		1.3	1.5	
	N	17.0	1.3	**	1.1	0.2	n.s.	1.0	0.4	n.s.
25	0	12.5	1.1		1.0	0.1		1.0	0.4	
	N	14.6	1.0	***	0.9	0.1	n.s.	0.6	0.1	*
157	0	15.5	1.4		1.0	0.3		0.9	0.4	
	N [2]	16.5	0.7	*	1.1	0.2	n.s.	0.9	0.3	n.s
106	0	9.1	4.9		0.8	0.1		0.9	0.3	
	N	16.6	2.9	***	0.8	0.1	n.s	1.1	0.7	n.s.

Exp.	Treat-ment	Ca_{tot} g/kg	s.d.	p	Mg_{tot} g/kg	s.d.	p	C_{tot} g/kg	s.d.	p
113	0	9.0	2.6		3.1	0.9		493.3	71.3	
	N	7.6	2.5	n.s.	2.6	0.9	n.s.	564.0	35.7	*
26	0	4.9	1.2		1.6	2.7		602.3	22.6	
	N	5.2	0.7	n.s	1.6	1.0	n.s.	604.2	26.2	n.s.
25	0	2.9	0.4		0.9	0.7		577.1	17.3	
	N	3.6	0.6	**	0.9	0.2	n.s.	580.5	8.9	n.s.
157	0	2.5	0.8		1.1	0.7		585.1	30.7	
	N [2]	3.4	0.9	n.s.	2.8	2.4	n.s.	582.5	16.1	n.s.
106	0	1.8	0.6		0.8	0.3		497.6	264.4	
	N	3.4	1.2	[1] *	1.4	0.6	[1] *	613.9	76.2	n.s.

[1] based on ln-transformed data
[2] n = 5

The C/N ratio of the humus layer on the fertilized plots varied from 27 to 40 and on the control plots from 30 to 55. The C/N ratios were significantly lower on fertilized plots than on the controls (Table 4).

3.2 Effects of Nitrogen Addition on Ground Vegetation

On the control plots the biomass of the bottom layer (mosses and lichens) was more than half the total biomass of the ground vegetation (Fig. 4). On all site types nitrogen fertilization decreased the biomass of mosses and lichens (Fig. 5).

Dwarf shrubs, which are the dominant field layer species in boreal forests, did not benefit from addition of nitrogen. Nitrogen addition decreased the biomass of *Vaccinium myrtillus* and *Vaccinium vitis-idaea* on mesic site types (Exp. 25 and 26). On the poor sites, however, *Vaccinium vitis-idaea* benefited from nitrogen addition, while the biomass of *Calluna vulgaris* was decreased by fertilization (Fig. 6). There was no change in the biomass of *Linnaea borealis* due to fertilization. On the poor sites (Exp. 52 and 106) fertilization increased the total biomass of dwarf shrubs slightly (Fig. 4).

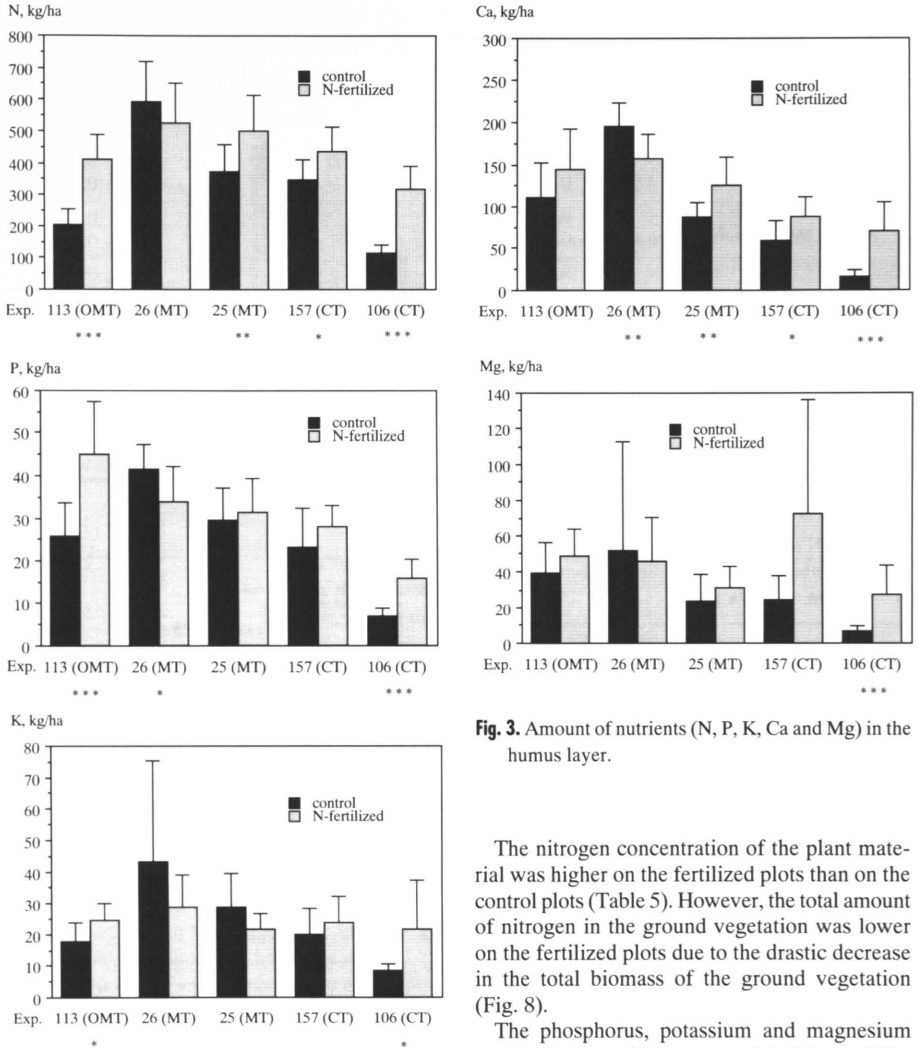

Fig. 3. Amount of nutrients (N, P, K, Ca and Mg) in the humus layer.

The biomass of grasses seemed to increase with nitrogen fertilization, but differences between treatments were significant only in Experiment 52 (Fig. 7). *Rubus idaeus*, which is the nitrogen-demanding species, was found only on the nitrogen-fertilized plots. Nitrogen fertilization had no clear effect on the total biomass of herbs (Fig. 7).

The nitrogen concentration of the plant material was higher on the fertilized plots than on the control plots (Table 5). However, the total amount of nitrogen in the ground vegetation was lower on the fertilized plots due to the drastic decrease in the total biomass of the ground vegetation (Fig. 8).

The phosphorus, potassium and magnesium concentrations of plant material did not differ significantly between treatments, but in some cases the calcium concentrations were lower on the fertilized plots (Mäkipää 1993). Due to the decrease in biomass, the total amounts of these nutrients (P, K, Ca and Mg) bound by ground vegetation were lower on the fertilized plots (Fig. 8).

The litterfall of the ground vegetation was estimated based on the biomass. It was assumed

Table 3. Concentrations of the extractable nutrients of the humus layer on the basis of organic matter (0 = control and N = fertilized with nitrogen. $n_0 = n_N = 10$).

Exp.	Treatment	P g/kg	s.d.	p	K g/kg	s.d.	p	Ca g/kg	s.d.	p	Mg g/kg	s.d.	p
113	0	0.12	0.05		0.91	0.17		7.75	2.58		0.51	0.11	
	N	0.14	0.04	n.s.	0.74	0.12	*	6.44	1.70	n.s.	0.67	0.09	**
26	0	0.19	0.06		0.68	0.23		3.68	1.06		0.43	0.13	
	N	0.20	0.06	n.s.	0.76	0.21	n.s.	4.24	0.61	n.s.	0.66	0.09	***
25	0	0.27	0.06		0.75	0.11		2.51	0.35		0.41	0.05	
	N	0.24	0.03	n.s.	0.59	0.08	**	3.02	0.41	**	0.65	0.13	***
157	0	0.12	0.04		0.68	0.18		2.23	0.41		0.27	0.04	
	N 1)	0.09	0.03	n.s.	0.52	0.09	n.s.	2.50	0.41	n.s.	0.51	0.21	n.s.
106	0	0.13	0.05		0.71	0.28		0.94	0.37		0.23	0.04	
	N	0.09	0.04	n.s.	0.60	0.14	n.s.	2.01	0.35	***	0.55	0.09	***

1) $n_N = 5$

Table 4. C/N ratios of the humus layer by experiment and treatment (0 = control and N = fertilized with nitrogen. $n_0 = n_N = 10$).

Exp.	Treatment	C/N ratio	s.d.	p
113	0	30.0	1.7	
	N	26.5	1.4	***
26	0	42.8	6.2	
	N	35.8	3.6	**
25	0	46.4	3.5	
	N	40.0	2.4	***
157	0	39.0	2.7	
	N 1)	35.4	1.4	*
106	0	54.8	3.2	
	N	37.3	2.4	***

1) n = 5

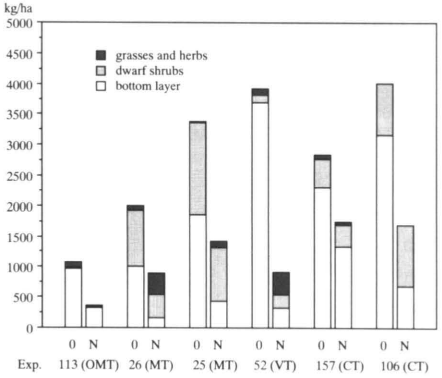

Fig. 4. Effect of nitrogen input on distribution of the biomass of ground vegetation. The bottom layer includes mosses and lichens; the dwarf shrubs of this study are *Vaccinium myrtillus*, *V. vitis-idaea*, *Calluna vulgaris* and *Linnaea borealis*.

that the litterfall equals the annual production of the leaves and shoots. The shoots of *Hylocomium* and *Pleurozium* usually contain three living segments, each of which represents one year's growth (Tamm 1953). Thus the quantity of annual litter produced by the bottom layer was assumed to be 1/3 of the biomass. Mälkönen (1974) demonstrated that the proportion of the biomass made up of the current year's shoots was 18–24 % for *Calluna vulgaris*, 35–38 % for *V. vitis-idaea* and 41–51 % for *Vaccinium myrtillus*. In this study the litterfall of these species was assumed to be 1/4, 1/3 and 1/2 of the biomass, respectively. The litterfall of *Rubus idaeus* was assumed to be 3/4 of the biomass. All the above-ground parts of grasses and herbs are annual, and they were assumed to turn completely into litter.

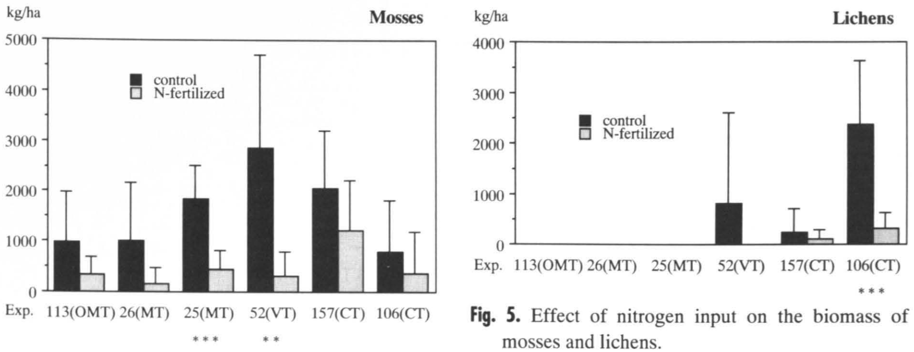

Fig. 5. Effect of nitrogen input on the biomass of mosses and lichens.

Table 5. Nitrogen concentrations of plant species and groups.

Exp.	Treatment	Mosses g/kg	s.d.	p	Lichens g/kg	s.d.	p	*V. myrtillus* g/kg	s.d.	p	*V. vitis-idaea* g/kg	s.d.	p	*Rubus idaeus* g/kg	s.d.	p
113	0	14.9	3.5		–			14.1	a)		10.8	a)		–		
	N	19.3	a)		–			–			–			–		
26	0	13.9	2.4		–			11.8	0.8		9.5	0.8		–		
	N	16.8	a)		–			12.2	2.0	***	8.4	a)		17.8	3.8	
25	0	10.4	2.1		–			9.0	1.3		8.1	0.8		–		
	N	14.9	1.7	***	–			10.9	2.2	*	10.0	a)		–		
52	0	9.7	1.6		5.8	0.8		1.6	a)		9.3	0.3		–		
	N	16.0	a)		–			–			10.7	1.5	n.s.	22.8	a)	
157	0	12.6	1.1		8.0	a)		8.1	a)		8.8	0.9		–		
	N	14.2	2.4	n.s.	7.5	a)		9.2	a)		9.7	0.7	***	–		
106	0	8.4	0.4		5.6	1.1		–			9.0	0.8		–		
	N	9.2	a)		12.2	a)		–			10.0	1.7	n.s.	–		

Exp.	Treatment	*Calluna vulgaris* g/kg	s.d.	p	*Linnaea borealis* g/kg	s.d.	p	Herbs g/kg	s.d.	p	Grasses g/kg	s.d.	p
113	0	–			–			23.8	a)		11.6	a)	
	N	–			–			–			21.0	a)	
26	0	–			12.5	a)		13.5	a)		12.8	a)	
	N	–			11.5	a)		17.9	a)		18.4	a)	
25	0	–			7.9	a)		14.2	a)		11.5	a)	
	N	–			13.2	a)		18.2	a)		11.5	a)	
52	0	10.4	a)		–			21.6	a)		12.6	a)	
	N	–			–			20.8	a)		18.4	3.8	
157	0	10.3	a)		–			17.8	a)		12.5	a)	
	N	10.0	a)		–			–			14.7	a)	
106	0	8.9	0.8		–			–			–		
	N	11.5	0.7	***	–			–			–		

a) 10 samples were combined for analysis (n = 1)

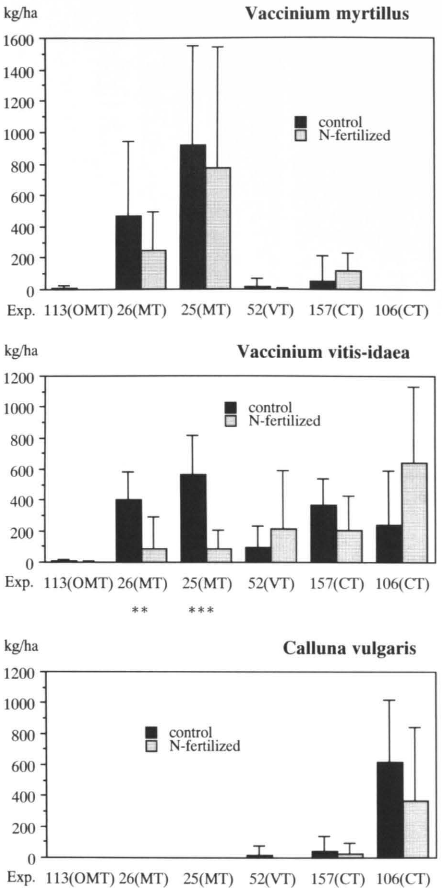

Fig. 6. Effect of nitrogen input on the biomass of dwarf shrubs (*Vaccinium myrtillus*, *V. vitis-idaea* and *Calluna vulgaris*).

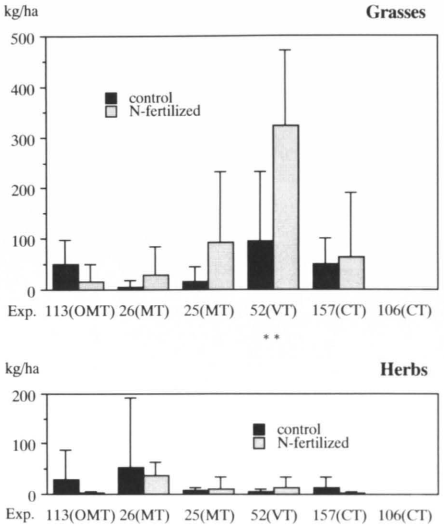

Fig. 7. Effect of nitrogen input on the biomass of grasses and herbs.

Nitrogen input decreased the total litter production of the ground vegetation. In Scots pine stands the total litterfall of the ground vegetation on fertilized plots was only about half (40–65 %) and in Norway spruce stands only 30 % of that on control plots. The residues of mosses formed the main part of the total litterfall. Nitrogen input changed the litterfall of the field layer only slightly, and the proportion of the herbs was minimal. On younger Scots pine stands (Exp. 26 and 52), however, the litter of *Rubus idaeus* was increased by fertilization. Nitrogen input increased the litterfall of the field layer on the *Vaccinium*-type forest (Exp. 52), where the estimated litterfall from *V. Vitis-idaea*, *Rubus idaeus* and grasses was increased.

4 Discussion

Addition of nitrogen increased the amount of organic matter in the humus layer. The reason for this increase may be the increased litterfall from the tree stand and from the ground vegetation. The biomass of needles has been reported to increase after fertilization (Binkely 1986), and needle litterfall also increases (Miller et al. 1976). The effects of fertilization on the litterfall of ground vegetation are not well known. Fertilization increases the annual production and consecutive the litterfall of grasses and herbs. There is also some evidence that fertilization decreases the turnover time for the leaves of evergreen shrubs (Karlsson 1985, Simms 1987); therefore the litter produced by dwarf shrubs is increased. In this study the estimated litterfall of the field

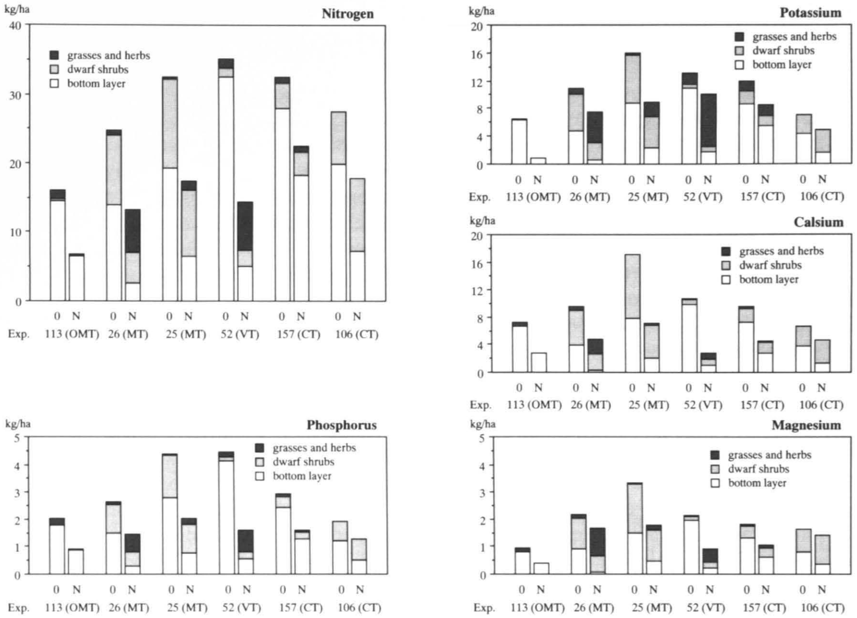

Fig. 8. Effect of nitrogen input on distribution of nutrients (N, P, K, Ca and Mg) in ground vegetation.

layer changed only slightly as a result of fertilization. The major changes occurred in the litter production of the mosses, which decreased after fertilization.

The aboveground litter production can explain only part of the increase in the amount of organic matter in the humus layer (Nohrstedt et al. 1989, Prescott et al. 1992). Furthermore, it is known that root production and the amount of decaying roots decrease after fertilization (Ahlström et al. 1988). There may also be a decrease in microbial biomass and activity (Söderström et al. 1983, Nohrstedt et al. 1989, Martikainen et al. 1989), resulting in slower decomposition of the litter on fertilized plots than on the control plots (Prescott et al. 1992). Although nitrogen fertilization increases the number or biomass of microbes and microbial activity immediately after its addition (Salonius 1972, Roberge 1976, Foster et al. 1980, Söderström et al. 1983), the biomass and activity of microbes may decrease over time, even to a level below that in the unfertilized soil (Foster et al. 1980, Söderström et al. 1983, Martikainen et al. 1989). This indicates that microbial activity in decaying materials is limited more by availability of carbon than by availability of nutrients (Flanagan and Van Cleve 1983, Prescott et al. 1992), and a supply of nitrogen does not accelerate decomposition.

The total amounts of nutrients (N, P, K, Ca and Mg) bound by the humus layer were greater on fertilized plots due to the increase in the amount of organic matter. Most of the added nitrogen is known to be immobilized in the forest soil, mainly in the humus layer (Melin and Nömmik 1988, Nohrstedt 1990). In this study nitrogen fertilization increased the nitrogen concentration in the organic matter, but the increase in the amount of organic matter was more important in controlling the amount of nitrogen in the humus layer.

Nitrogen input decreased the total biomass of the ground vegetation; in particular, the biomass of mosses decreased. Under closed canopy, the bottom layer (mosses and lichens) forms the major part of the aboveground biomass of the ground vegetation. The effects of nitrogen fertilization on the estimated percentage cover of the vertical projection of plant species have been studied and a decline in the moss cover after nitrogen fertilization has been reported in several studies (e.g. Mälkönen et al. 1980, Gerhardt and Kellner 1986, Kellner and Mårshagen 1991). After nitrogen fertilization, mosses may suffer from increased litter production and shading. Furthermore, symptoms of toxic effects of nitrogen fertilizers were observed in fertilization experiments. Mosses were turned brown shortly after application of nitrogen fertilizers (Gerhardt and Kellner 1986). Nygaard and Abrahamsen (1991) observed a reduction in mosses due to contact with acid rain, and similar observations have also been reported by Hutchinson and Scott (1988). Press et al. (1986) showed that nitrogen supply has a deterious effect on the growth of bryophytes.

Destruction of the moss cover may, in turn, affect the temperature and moisture content of forest soils. The moisture content and temperature of the humus layer fluctuate more rapidly on a forest floor that is not insulated by a layer of moss. It is known that the microbial activity of forest soil decreases with decreasing temperature and moisture content (Persson 1989, Tietema et al. 1992). Thus, destruction of the bottom layer (mosses) may be unfavorable for decomposition of the humus layer, especially under dry conditions.

The effect of the addition of nitrogen on dwarf shrubs varied among the different species and site types. Dwarf shrubs, which are adapted to limited amount of nitrogen, have a limited ability to use added nitrogen (Chapin et al. 1986). On the mesic sites (*Myrtillus*-type forests) the biomass of *Vaccinium myrtillus* and *Vaccinium vitis-idaea* decreased. On dry and poor sites, however, *V. vitis-idaea* benefits from the additional nitrogen while the biomass of *Calluna vulgaris* decreases. It is known that nitrogen deposition is one of the main reasons for a decline of heather species (*C. vulgaris* and *Erica terralix*) and succession from heather-dominated to grass-dominated heathlands (Roelofs 1986). *Calluna vulgaris* seems to be sensitive to nitrogen input, but the other reason for the decline in *C. vulgaris* under closed canopy may be the change in light conditions (Kellner and Mårshagen 1991).

There have been several reports of increased abundance (cover percentage) of grass species due to fertilization (Mälkönen et al. 1980, Gerhardt and Kellner 1986, Dirkse and Dobben 1989, Kellner and Mårshagen 1991). However, the importance of grasses and herbs in nutrient use have been overestimated, because the biomass of grasses is fairly low, even when the coverage is high. The results of this study show that the increase in the aboveground biomass of grasses is slight compared to the decrease in the biomass of mosses.

The nutrient content of the ground vegetation closely parallels the biomass of the vegetation. On the fertilized plots, owing to the decrease in biomass, the total amounts of nutrients bound by ground vegetation were lower than on the controls. The changes in nutrient concentrations due to fertilization were fairly small. According to the nutrient concentrations in the plant material, there were no nutrient imbalances.

A high proportion of the nitrogen added to forest ecosystems accumulates in the humus layer as organically bound nitrogen (Melin et al. 1983, Melin 1986, Melin and Nömmik 1988, Mälkönen et al. 1990, Nohrstedth 1990), thus forest soil may be a sink for nitrogen deposition. On the other hand, according to the results of this study, nitrogen input decreased the biomass of ground vegetation; and it was clearly demonstrated that ground vegetation under closed canopy does not respond positively to nitrogen input. Thus ground vegetation is not a sink for nitrogen deposition. With the high nitrogen input of this study, symptoms of nitrogen saturation have been observed; nitrogen input has not increased the production of ground vegetation, and nitrogen input is changing the abundance of various plant species.

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