COMPARISON OF NITRATE LEACHING UNDER SILVER BIRCH (*BETULA PENDULA*) AND CORSICAN PINE (*PINUS NIGRA SSP. LARICIO*) IN FLANDERS (BELGIUM)

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Abstract. In a forest in Flanders (Belgium), situated in a region of intensive livestock production, comparable stands of Corsican pine and silver birch were studied for (1) NH_4^+ and NO_3^- concentrations in throughfall water and soil solution and (2) depositions and leaching of NH_4^+ and NO_3^- to groundwater. In each stand, throughfall collectors and porous cup lysimeters at three depths (0.1m, 0.5m and 1m) were installed in three replicated sets. Throughfall concentrations of ammonium and nitrate were significantly different for both species as well as soil solution concentrations of nitrate at all depths. Under pine, nitrate concentrations of the soil solution at 1m depth clearly exceeded the Belgian critical level for drinking water (50 mg.l^{-1}). Under birch, this level was only sporadically exceeded. During the sampling period, the depositions of NH_4^+-N and NO_3^--N reached respectively 21.6 kg/ha and 6.3 kg/ha under birch and 81.3 and 15.2 kg/ha under Corsican pine. Nitrate-N leaching under silver birch amounted 25.4 kg/ha whereas 56.4 kg/ha was measured under Corsican pine.

1. Introduction

In large parts of Europe, high intensity livestock production is responsible for considerable emission rates of NH_3 (Asman et al., 1987). The local and regional variation however is high and depends on, among other factors, the distance to local emission sources. Since trees act as efficient filters, forests can capture high amounts of pollutants (van Breemen and van Dijk, 1988). Chronic atmospheric nitrogen deposition has resulted in N saturation of previously N-limited temperate forest ecosystems (Nihlgard, 1985; Agren and Bossata, 1988; Aber *et al.*, 1989). When a forest ecosystem becomes N saturated, the N availability exceeds the capacity of plants and soil microbes to accumulate N (Aber *et al.*, 1989) and nitrate will be leached and impair ground- and surface water (Nihlgard, 1985; Agren and Bossata, 1988). According to Gundersen et al. (1998), leaching of nitrate is a key parameter distinguishing N-limited and N-saturated forest ecosystems and it is a major concern in groundwater quality conservation.

Since aquifers underlying forested sand deposits are often used as source of high-quality drinking water (van Breemen and van Dijk, 1988), high depositions of NH_4^+ can threat drinking water supplies. Several studies in the

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Netherlands showed that the high nitrate concentrations found below the rooting zone of forest stands are now frequently observed in the upper meters of the deeper aquifers (van Breemen and van Dijk, 1988). Such observations indicate that local breakthrough of nitrate to the groundwater may be imminent. Nitrification of ammonium derived from atmospheric deposition does not only threaten drinking water pools but may also be harmful to the ecosystem itself, due to acidification, the loss of accompanying cations (calcium, magnesium and potassium) and/or mobilisation of toxic aluminium (van Breemen *et al.*, 1983; Ulrich, 1987; Cole *et al.*, 1992).

An effective measure to reduce the leaching of nitrate could be the conversion of homogenous coniferous forests to mixed species forests based on broad-leaved trees. Broad-leaved tree species such as *Betula* sp. and *Quercus* sp. are less efficient in capturing dry deposition than coniferous trees (Brown and Iles, 1991). Furthermore, hardwood in general, and birch and oak in particular, are species with a high N demand (Cole and Rapp, 1981). Several investigations indicate that conifers release higher amounts of nitrogen to groundwater than broadleaves (Matzner, 1988; de Vries and Jansen, 1994).

Despite the high emmision rates of nitrogen in Flanders, knowledge on nitrate leaching from Flemish forest ecosystems is scarce. The present paper aims at providing comparative information on depositions and leaching of NH_4^+ and NO_3^- from stands of Corsican pine (*Pinus nigra ssp. laricio*) and silver birch (*Betula pendula*).

2. Site description

The experiments were conducted in the nature reserve 'Hoogmoerheide' at Merksplas, in the northeastern part of Belgium (Flanders). The nature reserve is located in a flat area, with an altitude of 33 m above sea level. Average annual precipitation and temperature are 830 mm and 10.3°C respectively. The coarse sandy soils of this study area have a massive, compacted and cemented spodic B horizon and are classified as a Haplic Podzol (FAO, 1988). High rates of ammonia are emitted by intensive animal husbandry surrounding the reserve.

Hoogmoerheide covers 105 ha and is mainly dominated by heath. The forest consists of homogeneous stands of *Pinus nigra* ARNOLD *ssp. laricio* and *Pinus sylvestris* L. and deciduous stands with *Betula pendula* L.. Neighbouring stands of Corsican pine and silver birch of the same stand age, on the same parent material, similar soil type and history were selected. The humus type in the birch stand is a mull humus, in the pine stand a mor humus. The history of the stands was verified using historical topografic maps of 1775, 1850, 1871, 1887, 1928, 1961, 1970 and 1985. The vegetation shifted in 1850 from heath to Scots pine. From then on, the plots remained forested. The age of both of the selected stands is between 40 an 45 years. The Corsican pine stand was planted around

1955, while the birch stand developed naturally as the sub-layer of a Scots pine stand. The overstorey of Scots pine trees was cut around 1985. No herbaceous vegetation occurs in the Corsican pine stand, a low cover of *Deschampsia flexuosa* and *Molinia caerulea* (<10 %) occurs in the birch stand. Stand parameters of both stands are shown in Table I.

TABLE I

Stand characteristics for silver birch and Corsican pine at Merksplas, 1999

	silver birch	Corsican pine
Stand age (*yr*)	40-45	40-45
Stems ($N.ha^{-1}$)	1060	1280
Basal area ($m^2.ha^{-1}$)	16.2	45.2
Mean diameter (at 1.30m) (*m*)	0.13	0.20
Mean height (*m*)	14.4	16.1
Volume (m^3/ha)	111.4	365.3
Soil pH-H_2O		
0-0.1m	3.7	3.6
0.1-0.3m	3.9	4.2
0.5-1.0m	4.1	4.3
Soil C/N-ratio		
0-0.1m	30.0	31.2
0.1-0.3m	28.0	26.7
0.5-1.0m	14	15

3. Materials and methods

The experiment was set up as 3 replicated sets under Corsican pine and silver birch, each at a fixed distance of 50 meters from the forest border, to avoid the influence of forest edge on deposition (Draaijers et al., 1988; De Schrijver et al., 1999). Each set was equipped with 4 throughfall collectors and suction porous cup lysimeters at three depths. Bulk deposition was collected using 4 bulk collectors placed above the heath adjacent to the forest.

Throughfall and free field water were collected using polyethylene funnels (15-cm diameter) supported by and draining into two-litre polyethylene containers. The containers were placed below ground level to avoid growth of algae and to keep the samples cool. The use of a nylon wire mesh placed in the funnel prevented contamination by large particles. On each sampling occasion, the volume of water in every collector was measured in the field and collectors were replaced by distilled water-rinsed collectors. The four throughfall samples of each set were pooled to one sample. Stemflow water was not collected because of its low contribution to nutrient fluxes in pine (Neirynck, 1996) and young birch stands. Suction porous cup lysimeters were installed at depths of 0.1, 0.5 and 1m. The applied suction was –50 kPa. Soil solution samples were not pooled but analysed separately. Water fractions were collected and measured fortnightly from September 1998 to April 1999 and monthly from May to August 1999.

All water samples were transported and stored at a temperature of maximum 5° C. The samples were filtered through Whatman GF/C filters and analysed within a week for NO_3^-, NH_4^+, pH, (using specific electrodes) and K, Ca, Mg, Na and Al (Flame atomic absorption spectro-photometry).

Deposition rates of ammonium and nitrate were calculated for the period September 1998 - August 1999 by multiplying the measured amount of throughfall water with the element concentration. The seepage water output was calculated for the same period based on concentrations of elements in the soil solution at 1m depth. The influence of the roots on soil solution was assumed to be negligible at this depth. Since meteorological parameters were not measured in the stands, the amount of seepage output was calculated using the mean ratio's of Na^+ in the canopy throughfall and seepage water, assuming conservative behaviour of Na. This was done under the assumption that, related to canopy throughfall, the concentrations of Cl^- and Na^+ in seepage water are influenced exclusively by evapotranspiration and by electrostatic interaction with soil particles or roots, but not by active plant uptake, and that the release of these elements by mineral weathering is negligible within the periode of investigation (Thomas and Büttner, 1998). Throughfall fluxes of Na were assumed to balance drainage fluxes of Na. Output rates for nitrate and ammonium were calculated by multiplying the computed amount of seepage water with the element concentration of the soil solution at 1m depth. Since samples from this depth were regarded as representative for the soil solution leaving the root zone, calculations of output rates were based on these data.

The amounts of throughfall water and drainage water under pine and birch were averaged for the three replicated sets and were compared by use of a paired t-test. The data-set of ammonium and nitrate in throughfall and soil solution was analysed as a repeated measures design with species in the between stratum and time in the within stratum of an Univariate ANOVA (Mathsoft, 1997). This analysis was conducted for (1) the whole year (September 1998 to August 1999, (2) the growing season (September to October 1998 and May to August 1999) and (3) the dormant season (November to April).

4. Results

4.1 WATER FLUXES

The quantities of precipitation, canopy throughfall and seepage water from September 1998 to August 1999 are shown in Table II. The amounts of throughfall water under pine and birch were significantly different ($p = 0.000$). The birch stand canopy passed 175 mm more water than the pine stand, which is due to differences in interception capacity caused by a lower Leaf Area Index and the deciduous character. The quantity of seepage water under both stands was not significantly different.

TABLE II

Total precipitation, canopy throughfall and seepage water (mm) (September 1998 to August 1999)

Water fraction	Corsican pine (mm)	silver birch (mm)	t	p
Precipitation	979.6			
Canopy throughfall	638.3	814.1	4.7	0.000
Seepage water	363.3	383.0	0.1	0.989

4.2. NITROGEN INPUT

4.2.1 N-CONCENTRATIONS

Concentrations of ammonium and nitrate in free field water were lower than in throughfall water during the whole year (Figure 1). Concentrations of both forms of nitrogen were considerably higher in pine than in birch throughfall, which was caused by differences in dry deposition and interception capacity.

Average concentrations of ammonium and nitrate in throughfall water were higher in the pine stand than in the birch stand (Table III). The same conclusion could be drawn for the data set being split up in the growing season (September to October 1998 and May to August 1999) and the dormant season (November 1998 to April 1999). Average throughfall concentrations of ammonium and nitrate are for both species, except for nitrate in pine throughfall, highest for the dormant season.

ANOVA of throughfall water chemistry detected a significant effect of tree species on concentrations of nitrate (Table IV) and ammonium (Table V) for the whole year, the growing and the dormant season. Also time was a significant factor for both forms of inorganic nitrogen in throughfall water. The interaction between tree species and time was, except for nitrate concentrations during the dormant season, significant for both elements, indicating that for both species the deposition pattern differed in time.

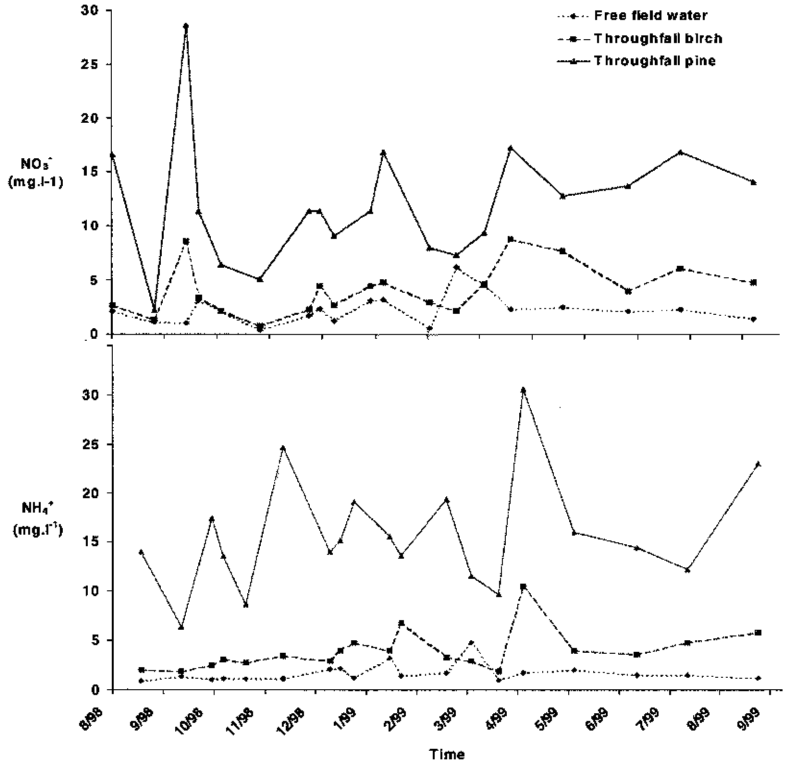

Fig. 1. Average concentrations of ammonium and nitrate in free field and throughfall water under Corsican pine and silver birch

TABLE III

Average concentrations (± standard deviation) of ammonium and nitrate in free field water, throughfall water and soil solution at 0.1m, 0.5m and 1m depth under Corsican pine and silver birch for the whole year, the growing season and the dormant season

	Whole year		Growing season		Dormant season	
	silver birch	Corsican pine	silver birch	Corsican pine	silver birch	Corsican pine
NH_4^+	4.6 ± 3.0	14.8 ± 7.9	4.1 ± 2.4	13.1 ± 9.2	5.0 ± 3.4	16.3 ± 6.6
NO_3^-	4.2 ± 2.5	11.4 ± 8.1	2.6 ± 1.2	11.8 ± 8.8	5.6 ± 2.5	10.1 ± 5.9
Soil solution at 0.1m						
NH_4^+	6.6 ± 8.3	11.1 ± 11.1	4.6 ± 4.6	15.5 ± 14.8	8.3 ± 10.1	7.5 ± 5.0
NO_3^-	30.0 ± 19.6	71.4 ± 44.8	30.9 ± 20.4	71.7 ± 48.7	29.3 ± 19.2	70.7 ± 31.4
Soil solution at 0.5m						
NH_4^+	2.3 ± 3.9	4.3 ± 4.3	2.7 ± 3.8	6.7 ± 3.9	1.9 ± 4.0	2.2 ± 3.6
NO_3^-	41.9 ± 28.5	67.8 ± 25.3	50.4 ± 29.9	70.5 ± 27.0	34.2 ± 25.5	59.2 17.1
Soil solution at 1m						
NH_4^+	0.5 ± 1.1	1.5 ± 2.3	0.6 ± 1.5	3.1 ± 2.7	0.4 ± 0.7	0.1 ± 0.1
NO_3^-	30.3 ± 13.3	77.8 ± 48.1	29.1 ± 16.8	84.7 ± 53.1	31.4 ± 9.4	55.6 ± 11.6

TABLE IV

Result of the ANOVA of nitrate concentrations in throughfall water and soil solution at 0.1m, 0.5m and 1m for the whole year, the growing season and the dormant season

	Tree species			Time			Interaction		
	dF	F	p	dF	F	p	dF	F	p
Throughfall									
Whole year	1	106.7	<0.001	16	12.2	<0.001	15	4.0	<0.001
Growing season	1	160.1	<0.001	8	16.6	<0.001	8	5.4	<0.001
Dormant season	1	17.3	0.014	7	8.7	<0.001	7	1.7	0.140
Soil solution at 0.1m									
Whole year	1	286.9	0.038	16	1.8	0.049	16	0.8	0.702
Growing season	1	53.0	0.018	8	1.8	0.110	8	1.1	0.370
Dormant season	1	51.5	0.006	8	0.9	0.524	8	1.0	0.469
Soil solution at 0.5m									
Whole year	1	1.3	0.457	16	5.6	<0.001	15	3.0	0.001
Growing season	1	5939.8	<0.010	8	2.5	0.040	7	0.6	0.730
Dormant season	1	13.2	0.022	8	1.9	0.090	8	1.6	0.150
Soil solution at 1m									
Whole year	1	27.6	0.120	16	4.9	<0.001	15	5.5	<0.001
Growing season	1	139.5	0.001	8	3.5	<0.001	7	5.1	<0.001
Dormant season	1	21.3	0.019	8	3.6	0.005	8	1.3	0.278

4.2.2 NITROGEN DEPOSITION

Nitrogen depositions via precipitation and throughfall water consisted mainly of ammonium (Table VI). Ammonium and nitrate depositions were clearly higher in the forest than at the open field. Nitrogen deposition in the Corsican pine stand amounted up to three times the deposition in the birch stand.

Bulk deposition of nitrate seemed to be equal for the dormant and the growing season, while ammonium was mainly deposited during the dormant season. Throughfall depositions of both N-forms were higher during the dormant season for both species.

TABLE V

Result of the ANOVA of ammonium concentrations in throughfall water and soil solution at 0.1m, 0.5m and 1m for the whole year, the growing season and the dormant season

	Tree species			Time			Interaction		
	dF	F	p	dF	F	p	dF	F	p
Throughfall									
Whole year	1	736.3	<0.001	16	9.8	<0.001	15	3.2	<0.001
Growing season	1	24.6	<0.016	8	4.8	<0.001	8	2.8	0.015
Dormant season	1	40.1	<0.008	7	56.7	<0.001	7	9.2	<0.001
Soil solution at 0.1m									
Whole year	1	0.9	0.437	16	3.6	<0.001	16	2.9	<0.001
Growing season	1	6.0	0.091	8	3.6	0.004	8	2.4	0.040
Dormant season	1	0.0	0.989	8	5.2	<0.001	8	1.0	0.478
Soil solution at 0.5m									
Whole year	1	1.9	0.266	16	5.8	<0.001	15	1.2	0.289
Growing season	1	6.3	0.087	8	10.2	<0.001	7	5.4	0.254
Dormant season	1	3.4	0.316	8	1.9	0.103	8	0.3	0.969
Soil solution at 1m									
Whole year	1	8.1	0.104	16	3.9	<0.001	15	2.9	0.002
Growing season	1	8.4	0.101	8	2.9	0.018	7	2.0	0.091
Dormant season	1	0.1	0.839	8	2.9	0.014	8	0.4	0.938

TABLE VI

Deposition and leaching at 1m of ammonium-N and nitrate-N (kg/ha) during the whole year (September 1998 to August 1999), the growing season (September 1998 to October 1998, May 1999 to August 1999) and the dormant season (November 1998 to April 1999)

	Whole year		Growing season		Dormant season	
Water fraction	NH_4^+-N (kg/ha)	NO_3^--N (kg/ha)	NH_4^+-N (kg/ha)	NO_3^--N (kg/ha)	NH_4^+-N (kg/ha)	NO_3^--N (kg/ha)
Precipitation	12.6	4.4	4.2	2.2	8.4	2.2
Canopy throughfall						
silver birch	21.6	6.3	9.2	3.7	12.4	2.6
Corsican pine	81.3	15.2	32.5	9.3	48.8	5.9
Seepage water						
silver birch	1.4	25.4	0.4	11.8	1.0	13.6
Corsican pine	3.3	56.4	1.9	21.4	1.4	35.0

4.3 NITROGEN OUTPUT

4.3.1 NITROGEN CONCENTRATIONS

Nitrate concentrations in the soil solution were during the whole year higher under pine than under birch at all depths (Figure 2, 3 and 4). Concentrations of ammonium in soil solution were low compared to nitrate and higher under pine than under birch. The concentrations of ammonium were still considerable at 0.1m and 0.5m depth. At 1m, ammonium was mainly consumed by nitrification, plant uptake, adsorption (cation exchange) and microbial assimilation

Also the average concentration of ammonium and nitrate in the soil solution were at all depths higher under pine than under birch (Table III). In the pine stand, average nitrate concentrations in the soil solution clearly exceeded the critical value of 50 ppm for drinking water. Under birch, this level was only exceeded at 0.5m during the growing season.

ANOVA of nitrate concentrations in the soil solution (Table IV) showed a significant effect of tree species at all depths. Time was at 0.5m and 1m of importance as well as the interaction between tree species and time. This indicates again a different time pattern in nitrate concentrations for both species.

ANOVA of concentrations of ammonium in soil solution did not detect a significant effect of tree species (Table V). Time however was significant determinant for soil solution ammonium. As can be seen in Figure 1, ammonium concentrations at 0.1 and 0.5m followed roughly the same fluctuations as in throughfall water. A significant interaction existed between tree species and time for the soil solution at 0.1m and 1m depth for the whole year, indicating a different pattern of ammonium concentrations in time.

4.3.2 LEACHING OF NITROGEN

Nitrogen leaching under both tree species consisted mainly of nitrate. Quantities of ammonium were low but not negligible. The quantities of nitrate-N and ammonium-N leaching under Corsican pine at 1m depth were up to twice those under silver birch (Table VI). During the dormant season, N-leaching was, especially under pine trees, considerably higher than during the growing season, although average nitrate concentrations were lower. This can be explained by a higher flux of drainagewater during the dormant season.

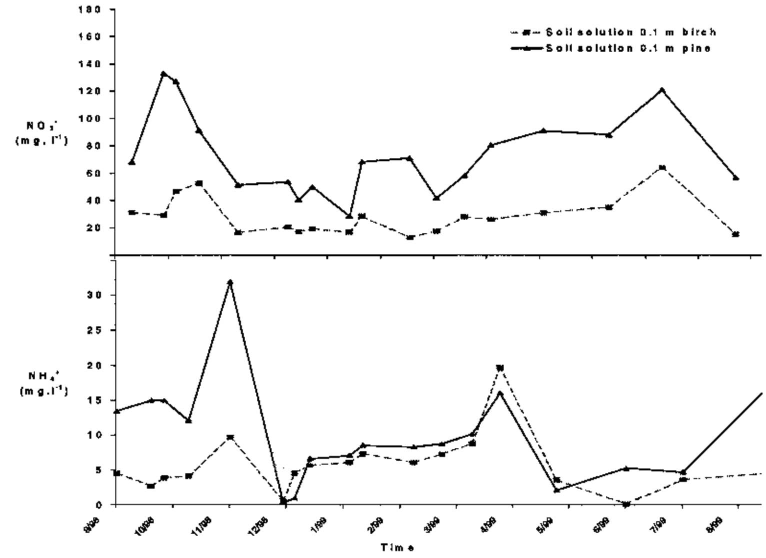

Fig.2. Average concentrations of ammonium and nitrate in the soil solution at 0.1m depth under Corsican pine and silver birch

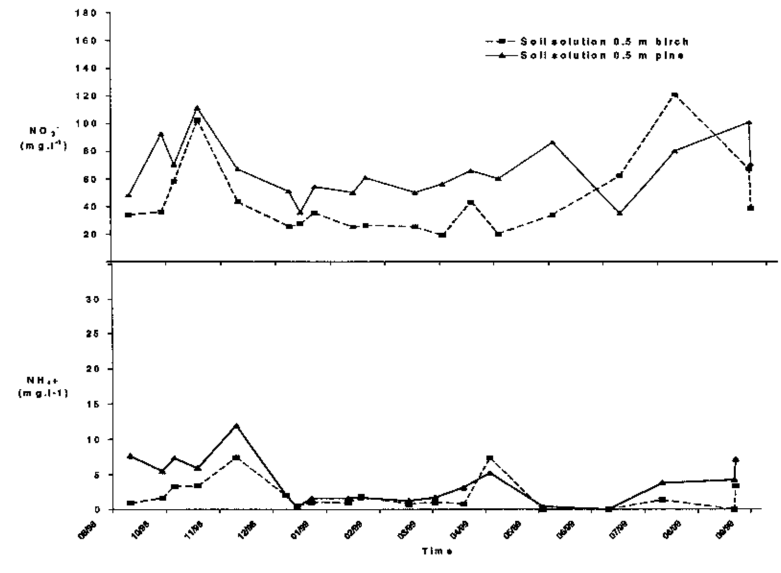

Fig.3. Average concentrations of ammonium and nitrate in the soil solution at 0.5m depth under Corsican pine and silver birch

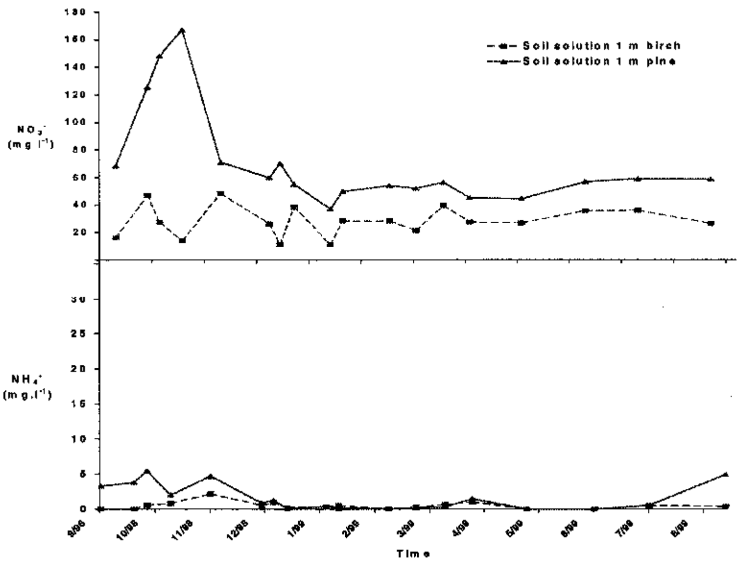

Fig.4. Average concentrations of ammonium and nitrate in the soil solution at 1m depth under Corsican pine and silver birch

5. Discussion

5.1 NITROGEN INPUT

Throughfall concentrations under Corsican pine were shown to be significantly different from those under silver birch. These results can be explained by both differences in dry deposition and interception capacity. The N-depositions in Corsican pine stands were more than three times higher than those in birch stands. This resulted from the lower efficiency of broad-leaved trees in capturing dry deposition. Leaves provide a less efficient trapping surface than needles and the filtering capacity of deciduous trees is reduced during the winter period (Brown & Iles, 1991).

Concentrations of pollutants in throughfall water are the result of several factors as emission rates, interception capacity of canopies and meteorological factors as precipitation, temperature, relative humidity and wind speed. This explains the significant impact of time on throughfall concentrations under both species. Despite the higher efficiency of tree canopies to capture air pollutants during the growing season, average concentrations of ammonium and nitrate were highest for the dormant season. This can be partly explained by higher emission rates of ammonia in autumn, winter and springtime when manure is spread on the fields. This hypothesis was confirmed by higher N-concentrations in precipitation during the dormant season. Due to the higher canopy filtering efficiency of conifers, higher air concentrations of NH_3 and NO_x resulted in higher throughfall concentrations in the pine stand. Throughfall depositions of ammonium-N and nitrate-N amounted respectively 21.6 kg/ha and 6.3 kg/ha in the birch stand and 81.3 and 15.2 kg/ha in the pine stand.

5.2 NITROGEN OUTPUT

Compared to nitrate, concentrations of ammonium in the soil solution were low. In the upper 1m of the soil under both species, most of the ammonium was nitrified, taken up by vegetation, adsorbed (cation exchange) or assimilated by microbes. Although there is some evidence that nitrification is inhibited in very poor soils under conditions of high NHx deposition (Van der Maas, 1985), a growing number of studies reported that nitrification can still occur in very acid soils (Van Praag and Weissen, 1973; Froment and Remacle, 1975; Gundersen and Rasmussen, 1990). High ammonium concentrations still appear at the upper 0.5m, indicating lacking ammonium uptake or absence of an active nitrifying community. Soils with C/N ratios > 25-30 and low nutrient concentrations are reported to be non-nitrifying (Gundersen and Rasmussen, 1990). The high C/N-ratio's of the forest floor and the upper mineral soil might be the reason for the slowing down of nitrification and the presence of ammonium in the upper 50 cm. A displacement of ammonium to a deeper horizon with lower C/N-ratio's could have been necessary to allow nitrification.

Nitrate concentrations in the soil solution were found to be significantly different for both species. Since nitrate is only weakly adsorbed on soil particle surfaces - especially in sandy soils which are low in clay content (Zöttl, 1990) - it is readily leached when it is not taken up by roots. The high concentrations of nitrate in the soil solution under Corsican pine and to a lesser degree under silver birch indicate that plant roots can not consume all nitrates and a surplus is leaching. Investigations by Matzner (1988) and De Vries and Jansen (1994) confirm these results. The quantity of nitrate-N leaching under the birch and the pine stand amounted respectively 25.4 and 56.4 kg/ha, while the leaching of ammonium-N reached 1.4 and 3.3 kg/ha respectively. The higher leaching of nitrate during the dormant season is the result of higher input by depositions, lower uptake by plant roots, higher mineralization rates of organic matter and subsequent nitrification of ammonium. As these processes are variable in time, the impact of tree species on nitrate concentrations is time dependent.

The lower output rates under birch stands can be explained by both a higher ammonium and nitrate retention capacity and a lower input rate of nitrogen. Based on this research, it is not possible to distinguish the relative importance of both factors. According to Cole and Rapp (1981), the uptake of nitrogen by temperate deciduous forests can be about 63% higher than by coniferous forests on the same soil conditions and in the same region. The annual requirement for nitrogen by temperate deciduous forests should be more than twice the requirement of temperate coniferous forests (Cole and Rapp, 1981). It is however clear that for both stands the retention capacity for nitrogen is exceeded as high amounts of nitrate are leaching to deeper soil horizons (nitrogen saturation) (Agren and Bossata, 1988). This lack of retention capacity makes the relation between incoming and outgoing nitrogen more direct. Research of Bredemeier et al. (1998) and Tietema et al. (1998) indicated that N output fluxes in nitrogen saturated forest ecosystems were largely determined by nitrogen inputs and up to 55% of the annual leaching of nitrate originates from the current nitrogen supply. This means that if one can reduce the input, e.g. by replacement of coniferous by broad-leaved species, the output of nitrate can drop rapidly.

6. General conclusions

It is clear that the input of nitrogen and the potential losses of nitrate in the birch stand are consistently lower than in the Corsican pine stand. The input of nitrogen was three times higher in the stand of Corsican pine. The quantities of nitrate and ammonium leaching under Corsican pine were more than twice of those leaching under silver birch.

Under pine, nitrate concentrations in the soil water at 1m exceeded the critical value of 50 ppm for drinking water. Under birch, this level was only sporadically exceeded.

According to these results, it can be stated that on poor sandy soils, a conversion of homogenous pine forests to mixed forests based on birch, can be an effective and useful measure to counteract nitrate leaching to the groundwater.

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