Element fluxes, forest floor characteristics and microbial activities under deciduous tree species after conversion of a Norway spruce (*Picea abies* (L.) Karst.) stand

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Introduction

Forest management is currently confronted with major questions, such as how to adapt plantation forests to a changing world. This questioning is not only essential with regard to forest health and productivity, but also within the frame of climate mitigation. In Europe, Norway spruce (*Picea abies*) monocultures have been planted beyond their assumed natural range. Furthermore, the characteristics of Norway spruce, such as susceptibility to windfall and forest dieback, as well as soil acidification have caused negative ecological impacts at many sites. Conversion of conifers into mixed stands has been suggested, in order to improve the stability and biodiversity of forest ecosystems.

The objective of the present study was to quantify element fluxes in throughfall, forest floor characteristics and nitrogen transformations, 12 years after conversion from *Picea abies* monocultures to a mixed stand. Measurements were performed under young and mature *Picea abies*, *Alnus glutinosa*, *Quercus robur* and *Sorbus aucuparia*. These trees have grown on the same site, sharing identical initial soil conditions and site history, so that potential effects on microbial processes and soil properties can be assigned to tree species.

We hypothesised that (1) soil properties and soil microbial activities would improve during conversion from coniferous to deciduous forest (2) the forest conversion affects throughfall deposition.

Site characteristics and history

The study area is located in the experimental catchment 'Robinette' (Fig. 1) in south-eastern Belgium (50°33'N, 6°04'E). After a second generation Norway spruce plantation, the catchment was partially clear-cut in 1996. Extensive afforestation with broadleaves adapted to specific site condition was performed in 1998. *Alnus glutinosa, Fagus sylvatica, Sorbus aucuparia, Betula pendula, Salix caprea* and *Quercus robur* were planted in 4 fenced plots, each of 2 ha size.

Soil: acid brown soil with moder to dysmoder humus type (Dystric Cambisol)
Elevation: between 470 and 530 m
Mean annual rainfall: 1300 mm
Mean annual temperature: 7°C
Surface area: 81 ha

Fig. 1. Fenced plot with broadleaved species ('Robinette')

Methods

Input fluxes

Bulk deposition (wet and dry deposition): 3 plots adjacent to the forest; 1 composite sample from 5 individual collectors in each plot (3 replicates). **Throughfall-Deciduous**: 4 fenced plots; 1 composite sample from 5 individual collectors under each species (*Alnus glutinosa*, *Quercus robur*, *Sorbus aucuparia, Betula pendula* and *Salix caprea*) (4 replicates). **Throughfall-Young *Picea*:** 4 plots across the catchment; composite sample from 5 individual collectors in each plot (4 replicates). **Throughfall-Mature *Picea***: 4 plots adjacent to the catchment; composite sample from 5 individual collectors in each plot (4 replicates). Chemical analyses: pH, K^+, NH_4^+-N, NO_3^--N.

Forest floor characteristics

Sampling: in September 2008;
1 composite sample from 5 soil cores (25 mm Ø; Of+Oh) taken around 6 trees (6 replicates) per selected **broadleaved species** (*Alnus*, *Quercus*, *Sorbus)* from one fenced plot (plot 1), 6 plots of **young *Picea*** across the catchment (same age as broadleaves) and in 6 plots of **open areas** (no trees, ground vegetation: *Molinia*) across the catchment.
Laboratory analyses: measured on sieved (4 mm) soil: pH (H_2O), organic matter content (weight loss at 450°C), exchangeable cations ($BaCl_2$ extraction), exchangeable acidity of H and Al (KCl extraction and titration).

Microbial activities

Net N mineralisation (net NO_3^--N and NH_4^+-N production during 28 days incubation), potential nitrification (shaken soil slurry method).

Statistical analyses

One-way ANOVA followed by post-hoc Tukey's test (SAS).

Results

Annual element fluxes

Table 1. Yearly water fluxes (mm year^{-1}) and element input (throughfall + stemflow) fluxes (kg ha^{-1} year^{-1}) under mixed deciduous and coniferous stands.

Fluxes	Tree species	Water fluxes	Elements			
			K^+	H^+	NH_4^+-N	NO_3^--N
Bulk deposition		1429 a	2.2 c	0.3 b	4.0 b	4.8 b
		(37)	(0.1)	(0.0)	(0.1)	(0.4)
Throughfall	**Deciduous**	1270 b	23.5 a	0.1 c	5.9 b	4.1 b
		(17)	(1.0)	(0.2)	(0.7)	(0.7)
	Young *Picea*	1034 c	24.3 a	0.1 c	6.9 b	10.3 a
		(79)	(2.8)	(0.0)	(1.1)	(1.9)
	Mature *Picea*	1029 c	16.3 b	0.4 a	11.3 a	11.1 a
		(32)	(1.3)	(0.0)	(1.9)	(0.6)

Values are means (n = 4) with standard error in brackets. Different small letters denote significant differences at $P < 0.05$.
* Seepage fluxes were calculated through Chloride Mass Balance

- Higher throughfall fluxes under deciduous compared to coniferous stands could be due to higher stand density and the evergreen character of *Picea*.
- Higher throughfall K^+ fluxes under broadleaves and young *Picea* than under mature *Picea is* likely explained by higher canopy leaching of young trees.
- H^+ and NH_4^+-N throughfall fluxes were higher under mature *Picea* than under other species and NO_3^--N deposition was higher under conifers than under broadleaves, probably due to higher interception of atmospheric particles or gases through higher LAI, tree height and evergreen foliage of *Picea*.

Forest floor characteristics

Table 2. Forest floor characteristics under broadleaves (plot 1), conifers and open areas (catchment).

Forest floor characteristics	Plot 1			Catchment		
	Alnus	*Quercus*	*Sorbus*	Young *Picea*	Mature *Picea*	Open areas
Organic matter (%)	64.6 ab	62.9 b	63.6 b	75.3 ab	81.7 a	71.7 ab
	(5.5)	(3.0)	(5.6)	(3.6)	(2.2)	(3.4)
pH (H_20)	3.7 a	3.6 a	3.8 a	3.8 a	3.6 a	3.7 a
ExAc H (cmol$_c$ kg^{-1})	3.0 b	3.7 b	3.2 b	5.4 a	5.3 a	4.0 ab
	(0.3)	(0.4)	(0.3)	(0.3)	(0.5)	(0.2)
ExAc Al (cmol$_c$ kg^{-1})	10.3 a	11.0 a	8.6 a	11.0 a	11.0 a	9.6 a
	(1.1)	(0.8)	(1.7)	(0.1)	(0.1)	(0.4)
Base saturation (%)	29.2 ab	30.0 ab	38.3 a	28.0 ab	20.0 b	38.2 a
	(3.3)	(2.5)	(7.2)	(4.0)	(3.0)	(2.0)
Ca^{2+} (cmol$_c$ kg^{-1})	4.4 ab	5.1 ab	5.9 ab	4.9 ab	2.9 b	7.0 a
	(0.5)	(1.3)	(1.4)	(0.1)	(0.5)	(0.6)
Mg^{2+} (cmol$_c$ kg^{-1})	0.8 a	0.9 a	1.4 a	1.1 a	0.8 a	1.4 a
	(0.1)	(0.1)	(0.3)	(0.2)	(0.1)	(0.1)

Values are means (n = 6) with standard error in brackets. Different letters denote significant differences at $P < 0.05$.
ExAc H = exchangeable acidity due to H; ExAc Al = exchangeable acidity due to Al;.

- Lower organic matter content under *Quercus* and *Sorbus* compared to mature *Picea* might be due to lower litter input.
- pH was not significantly different between species, likely because of the very acid conditions at the time of planting.
- Exchangeable acidity due to H^+ was decreased under broadleaves compared to conifers. This might be explained by the lower organic matter content under broadleaves, leading to lower organic acidity and/or decreased acidifying inputs. Exchangeable acidity due to Al^{3+} was similar under tree species.
- Higher base saturation under *Sorbus* and in open areas (under *Molinia*), could be explained by higher nutrient input from the litterfall and higher decomposition rate of these species.
- Higher exchangeable Ca^{2+} in open areas compared to mature *Picea* was likely due to higher Ca^{2+} turnover of *Molinia* as an annual plant. Exchangeable Mg^{2+} was similar under trees and in open areas.

Microbial activities

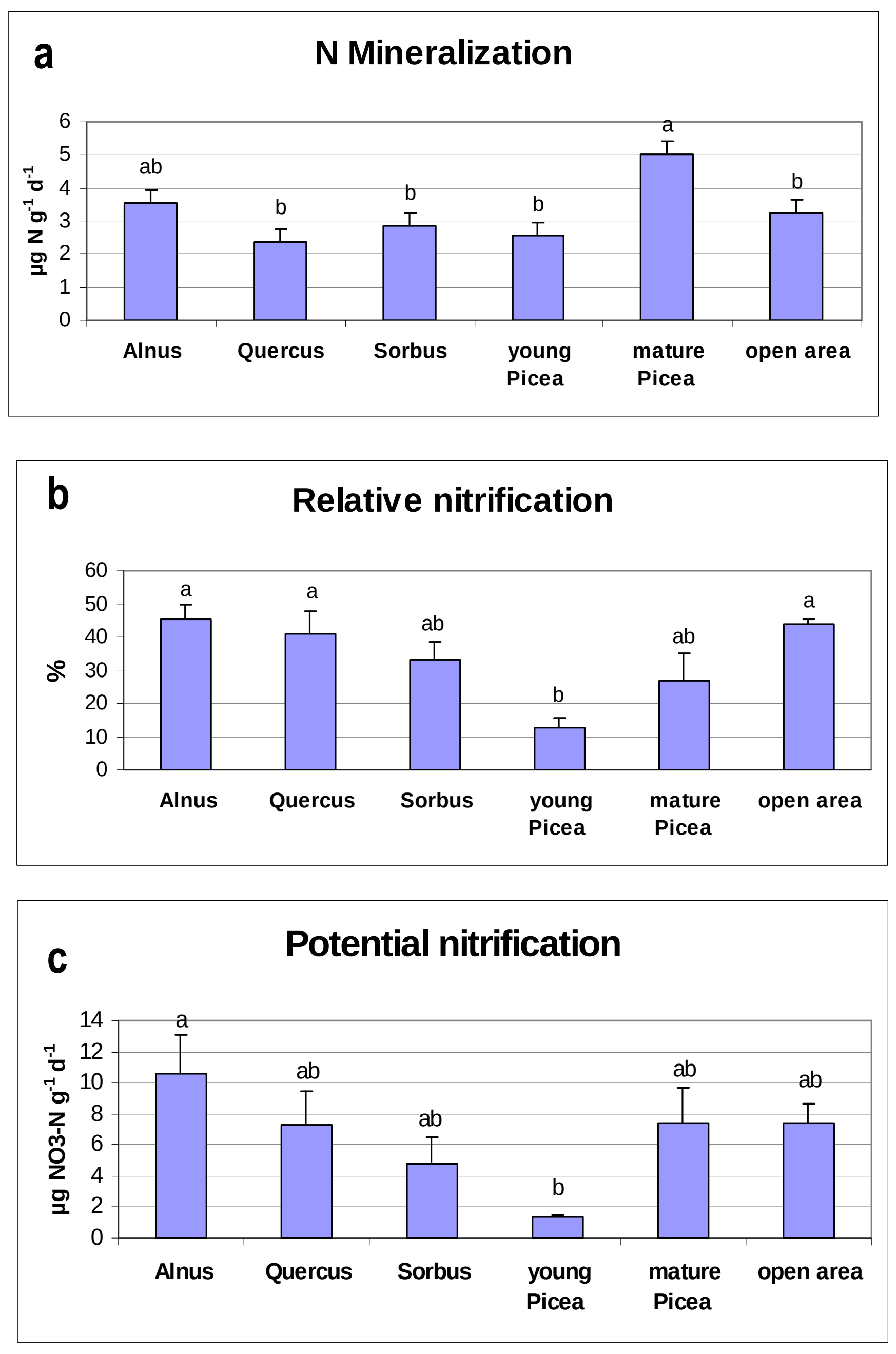

Fig. 2. Net N mineralization (a), relative nitrification (b) and potential nitrification (c) under broadleaves in plot 1, conifers and open areas. Different letters represent significant differences at $P < 0.05$. Values are referred as means (n=6). Error bars denote standard error.

a. Net N mineralization: higher N mineralization under mature *Picea* compared to other species except for *Alnus,* which may be linked to the higher organic matter content under *Picea.*

b. Relative nitrification: lower relative nitrification under young *Picea* compared to *Alnus*, *Quercus* and open areas.

c. Potential nitrification: higher potential nitrification below *Alnus,* compared to young *Picea,* could be due to ammonia enrichment in soil through symbiotic N_2 fixation. Lower potential nitrification below young *Picea* might be related to lower ammonium availability, as stand density and therefore tree uptake was higher for young spruce.

Conclusions

Results showed that, 12 years after conversion, tree species had a short-term impact on nutrient input fluxes and nutrient cycling in the upper soil layer. Decreased input fluxes of acidifying cations, lower soil organic matter content, as well as higher nutrient return in litter (not shown), under broadleaves might be responsible for the higher base saturation and lower exchangeable acidity due to protons measured under these species.

Conversion to broadleaves led to a significant decrease in N mineralization, as compared to the process under mature *Picea abies* trees, with no significant differences between the 3 broadleaved species studied. Potential nitrification was lowest under young *Picea abies* trees, probably due to high tree density. Results demonstrate that the conversion from *Picea abies* stands to broadleaves might offer the potential of improving soil chemical properties.

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