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Original article

Impact of dolomite lime on the ground vegetation and on potential net N transformations in Norway spruce (*Picea abies* (L.) Karst.) and sessile oak (*Quercus petraea* (Matt.) Lieb.) stands in the Belgian Ardenne

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Abstract – The impact of dolomite lime (5 T·ha^{-1}) on the ground vegetation and on potential net nitrogen (N) transformations was investigated in two Belgian forest ecosystems. Norway spruce (*Picea abies* (L.) Karst.) and sessile oak (*Quercus petraea* (Matt.) Lieb.) stands were situated in the Haute Ardenne (east Belgium) on acid-brown soil. The herb-layer floristic richness increased during the 2 years following liming, with the appearance of light and N-demanding species, which are also found in clear-cut areas or on road verges. Mosses reacted rapidly, showing a decrease acidophilous-dominant species and the establishment of some ruderal species. Six months after liming, the pH was significantly increased in the organic horizon of both stands and in the organomineral horizon of the oak stand. Soils originating from the two stands showed distinct responses in net NO_3^- production to the dolomite lime treatment. In the organic layer of the *Quercus* soil, net NH_4^+ production was decreased, NO_3^- production increased, and total N mineralisation remained unchanged. In the organomineral layer, NO_3^- production was increased. In the *Picea* soil, NO_3^- production was decreased in the organomineral soil layer. These results indicate the possibility of differences in the control of the N transformation processes occurring in the two sites. (© Inra/Elsevier, Paris.)

dolomite liming / forest / N mineralisation / nitrification / ground vegetation

Résumé – **Effet d'un amendement calcaro-magnésien sur la végétation et les transformations potentielles nettes de l'azote dans une pessière (*Picea abies* (L.) Karst.) et une chênaie (*Quercus petraea* (Matt.) Lieb.) en Ardenne belge.** L'impact de l'apport de 5 T ha^{-1} de dolomie sur la végétation et le cycle de l'azote a été étudié dans deux écosystèmes forestiers, situés en Ardenne belge, une plantation d'épicéas (*Picea abies* (L.) Karst.) et une chênaie à *Quercus petraea* (Matt.) Lieb. La strate herbacée s'enrichit lors des deux années qui suivent l'amendement d'espèces pionnières ou nitrophiles caractéristiques des trouées ou des bords de chemins. La strate muscinale réagit rapidement par la régression des espèces acidophiles dominantes et l'apparition discrète de neutrophiles ou de rudérales. Six mois après l'amendement, le pH a augmenté significativement dans l'horizon organique des deux plantations et dans l'horizon organo-minéral de la chênaie, La production nette de NO_3^- du sol a été influencée différemment par l'amendement dans les deux sites. Dans l'horizon organique de la chênaie, la production nette de NH_4^+ a été diminuée, la production de NO_3^- augmentée, sans modification de la minéralisation totale. Dans l'horizon organo-minéral, la production de NO_3^- a augmenté dans la chênaie, alors qu'elle diminuait dans la pessière. Ces résultats indiquent la possibilité de contrôles différents des transformations d'azote dans les deux sites. (© Inra/Elsevier, Paris.)

amendement calcaro-magnésien / forêt / minéralisation / nitrification / végétation

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1. Introduction

Forest decline symptoms observed in Europe since the early 1980s have affected Belgian forests particularly for Norway spruce (*Picea abies* (L.) Karst.) and oaks (*Quercus petraea* (Matt.) Lieb. and *Q. robur* L.). In southern Belgium, the problem is being studied by several university teams, in an interdisciplinary programme financed by the Walloon region (Section Nature and Forestry) [17].

Many biotic and abiotic factors govern forest dieback, the extent of which often depends on regions and tree species. Soil acidification due to atmospheric pollution, and subsequent nutritional deficiencies, appeared to be a major cause of the observed decrease in forest health. This was especially confirmed for Norway spruce growing on naturally poor acidic soils of the Belgian Ardenne [35, 36]. For *Q. robur* and *Q. petraea*, many studies revealed that the decline should be considered as a complex-causal phenomenon [15, 16, 23]. Among predisposing factors, nutritional deficiencies can weaken the trees, which are less able to support further stress. Fertilisation is then suggested, with a view to replenish the low level of some elements and to restore a nutritional balance consistent with the requirement of tree species [18].

Magnesium (Mg) deficiency is often pointed out as a major cause of decline in hardwood and coniferous forests [7, 20, 28, 34]. With the aim to raise low pH and to supply deficient Mg, dolomite lime is often suggested. In addition, the calcium and Mg supply may reduce aluminium in the soil cation exchange complex [26]. However, increasing soil pH could lead to increased nitrate and associated cation leaching [21].

In western Europe, many scientific research teams have investigated the effects of liming on different parts of forest ecosystems. The impact on health conditions and growth of timber-producing species has frequently been studied [5, 6, 25, 26]. The reaction of ground flora to liming has sometimes received attention [19, 27, 29, 31, 33]. However, the impact on mosses has rarely been investigated quantitatively [1].

We present a study on the modifications induced by a dolomite lime treatment on neighbouring Norway spruce and sessile oak forest stands. We focus on the botanical aspects, soil chemical parameters and potential nitrogen (N) mineralisation rates.

2. Materials and methods

2.1. Location and experimental design

The site was situated in the 'Hertogenwald' Forest (50°34' N, 6°02' E), eastern Belgium, at 440 m in altitude and with an annual rainfall of about 1 150 mm and a mean annual air temperature of 8.1 °C (source: Meteorological Royal Institute of Belgium).

The soil is acid-brown, derived from a primary Revinien quartzitic substrate, with white clay occurring at about 30 cm in depth. Two neighbouring stands with moder to dysmoder humus type and characterised by the presence of pseudogley were studied. The *P. abies* stand is second generation, planted in 1930. The original vegetation was a mosaic of deciduous forest and moorland. The ground vegetation is scattered, except in gaps where *Molinia caerulea*, *Pteridium aquilinum* and *Deschampsia flexuosa* essentially are more abundant. The moss layer is well developed, with various *Dicranaceae* species and *Polytrichum formosum* as dominant taxa. The *Q. petraea* stand originates from a coppice (with *Fagus* sp. and *Betula* spp.) dating from approximately 1930, when oaks were favoured. The herb layer is dominated by *M. caerulea* and *P. aquilinum*, with essentially *D. flexuosa*, *Vaccinium myrtillus* and *Carex pilulifera*. This vegetation can be regarded as a *Luzulo-Quercetum molinietosum*, according to Noirfalise [24]. Throughfall N inputs (under *Picea*) are about 20 and 15 $kg \cdot ha^{-1} \cdot year^{-1}$ NH_4^+-N and NO_3^--N, respectively.

Twelve square plots of 225 m^2 were established in each forest type around a central dominant or co-dominant tree, selected randomly. A minimum of 5 m between each plot was respected to prevent cross-contamination. Six plots of each stand were limed in April 1996 (*figure 1*) with 5 $T \cdot ha^{-1}$ of a dolomite lime suspension (55/40). To ensure homogeneity of lime distribution within the plots, it was applied manually with a portable spraying equipment, dispensing the suspension at a constant rate [14].

2.2. Soil chemical characteristics

Soil samples were taken from each plot 6 months after liming. The organic (4–8 cm in height) layer and the first 10 cm of the organomineral layer were separated for analyses. pH was measured potentiometrically on fresh soil in 1:2 (v/v) suspensions in demineralised water. P, K, Ca and Mg were measured at the 'Station provinciale d'analyses agricoles' of Tinlot (Belgium). Exchangeable cations were measured by the CSW-EDTA pH 4.65 method and spectrometric atomic absorption. Phosphorus was extracted with citric acid and measured by colorimetry.

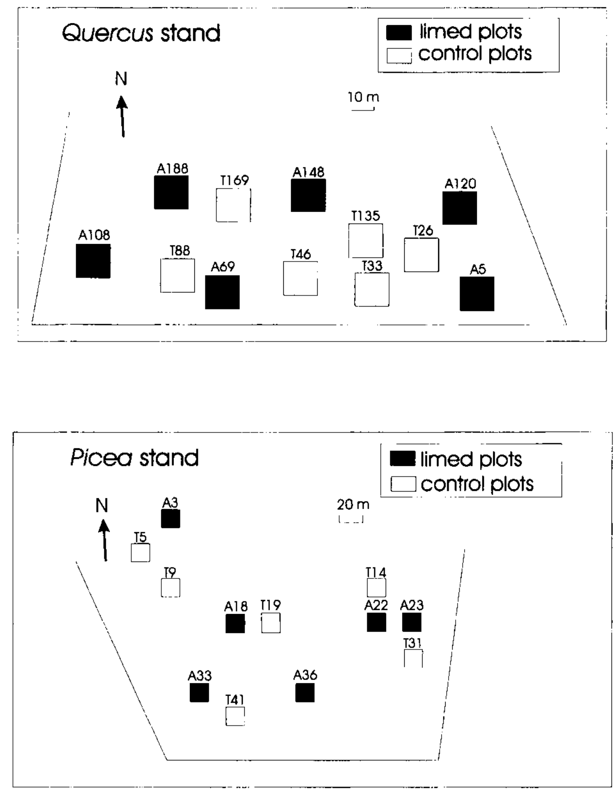

Figure 1. Experimental design. A = limed plots; T = control plots.

2.3. Potential N mineralisation

Two intact soil cores (PVC, 9.5 cm diameter) containing a 15-cm length of soil were taken from each plot in October 1996, at 1–3 m around the central tree. Samples of one plot were taken close to each other, to minimise spatial variability. One core per plot was immediately analysed for mineral N content and pH (see earlier). The second core was incubated for 60 d in the laboratory in the dark, at 80 % field capacity (100 % field capacity was defined as the water remaining after a water-saturated core was allowed to drain for 12 h) and 20 °C. The water content was adjusted every 4 d with distilled water.

For analyses, the cores were divided into organic (comprising Ol, Of and Oh) and organomineral (Ah; subsequently called mineral) layers, and weighed. They were homogenised manually. The water content was determined as weight loss at 105 °C.

Exchangeable NH_4^+-N and NO_3^--N were analysed after extraction (1 h) with 125 mL KCl 6 % of 20 g organic soil and 50 g mineral soil [2], followed by steam distillation of 20 mL of filtered extract. In a first step, ammonia was liberated from the extract in the presence of MgO and collected in a vessel containing boric acid combined with an indicator solution. In the remaining filtered extract, NO_3^--N was reduced to NH_4^+-N in the presence of Dewarda's alloy, distilled and collected in a second receiving container. NH_4^+-N was then analysed by titration with 0.005 N H_2SO_4 [8]. Previous analyses had shown NO_2^--N concentrations to be insignificant [9].

Net N mineralisation, ammonium and nitrate production are expressed as the difference between contents after and before incubation. They are expressed as mg N per 100 g dry weight produced during 60 d. The use of cores of a known diameter allowed productions on an areal basis to be calculated and data for 60 d were multiplied by 6.08 to provide annual estimates. Within the two stands significant differences between limed and control plots were analysed with a *t*-test [30].

2.4. Ground vegetation survey

The herb layer was listed using the Braun–Blanquet method on the 13 × 13 m inside surface of each plot (leaving a 1-m border along the plot boundaries). Quantitative data were provided using a 'point-intercept' method [22] and will be described later.

The moss layer survey was conducted on 25 small permanent quadrats of 50 × 50 cm, systematically installed on the soil surface in each plot. Frequency of moss and liverwort species in a plot was estimated by the number of quadrats (from a total of 25) where the species occurred. A frequency index was then affected to the species, as follows: 1 = species present in 1–5 quadrates in the plot; 2 = 6–10; 3 = 11–15; 4 = 16–20; 5 = 21–25.

Data concerning bryophytes on stumps and trunks were also collected.

3. Results and discussion

3.1. Soil chemical characteristics

The dolomite lime treatment resulted in a significant ($P < 0.05$) pH increase in both layers of the *Quercus* soil (*table I*). pH in water was increased by nearly 1 unit in the organic layer (pH_{H2O} 5.2). In the mineral layer, the pH increase was less pronounced but still significant. The pH increase in the organic layer of the *Picea* stand was similar to that of the *Quercus* stand. In the mineral layer of this stand, pH did not change significantly. The

Table I. pH_{H_2O}, P and exchangeable cations (mean ± standard deviation, mg·100 g^{-1} dry weight) 6 months after liming in the organic (org.) and organomineral (min.) layers of *Quercus* and *Picea* plots.

		Quercus		*Picea*	
		Control	Limed	Control	Limed
P[1]	org.	17.2 ± 1.5	23.5 ± 4.9*	12.5 ± 2.5	16.3 ± 3.7
	min.	7.2 ± 1.0	9.3 ± 2.2	10.3 ± 2.7	9.7 ± 2.5
K[1]	org.	68.0 ± 11.6	69.5 ± 9.8	34.2 ± 4.2	33.7 ± 4.9
	min.	15.2 ± 5.3	14.5 ± 4.5	20.7 ± 7.8	15.2 ± 6.8
Mg[1]	org.	24.2 ± 4.4	156.8 ± 10.4***	14.8 ± 2.6	138.8 ± 33.1***
	min.	7.0 ± 1.7	34.3 ± 12.6**	6.8 ± 0.7	20.6 ± 5.1**
Ca[1]	org.	136.3 ± 36.2	427.3 ± 71.4***	92.7 ± 25.8	334.7 ± 80.4***
	min.	18.7 ± 9.3	70.7 ± 28.3**	14.7 ± 5.3	39.6 ± 11.9**
pH[2]	org.	4.3	5.2***	3.9	4.6***
	min.	4.0	4.4**	3.9	3.9

[1]Analyses by 'Station provinciale d'analyses agricoles', Tinlot; [2]Analyses by 'Laboratoire d'écologie microbienne', Liège.
* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

treatment rapidly increased the exchangeable Ca and Mg contents of the organic and organomineral layers in both *Quercus* and *Picea* stands. The other essential elements remained unchanged, except for P which increased in the organic layer of the limed plots under *Quercus*.

These results also clearly show that the Ca content of the mineral layer in control plots of both *Quercus* and *Picea* soils should be considered as deficient or at least not optimum, according to the limit of 30 mg·100 g^{-1} suggested by various authors (e.g. [11]).

3.2. Potential N mineralisation

Potential net N transformations were affected differently by the lime treatment in the two stands (*figure 2*). Net NO_3^--N production significantly increased in the organic layer of the *Quercus* soil, with a significant reduction in NH_4^+-N production. Total net N mineralisation was not affected. In the mineral layer of the *Quercus* soil, the net NO_3^--N production also significantly increased. In the *Picea* soil, a decrease in the net NO_3^--N production in the mineral soil layer ($P = 0.07$) was the only significant effect. These results clearly demonstrate that moderate doses of dolomite lime (5 T·ha^{-1}) can modify potential net N transformations in the forest soil of the Belgian Ardenne. Responses differed between two adjacent plots with similar humus form and on the same parent material. Six months after liming, potential net NO_3^--N production increased in the organomineral layers of soil originating from a *Q. petraea* stand, whilst a

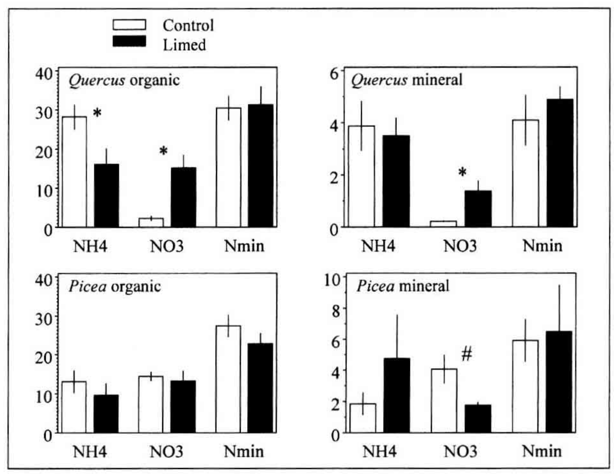

Figure 2. Potential net NH_4^+-N (NH4), NO_3^--N (NO3) and total mineral N (Nmin) production (mg N·100 g^{-1}·60 d^{-1}) in the organic and mineral soil layers from *Quercus* and *Picea* stands, 6 months after liming; mean ± standard error of the mean, *$P < 0.05$, # $P < 0.1$.

decrease was observed in the mineral soil of a *P. abies* soil. Increased nitrification without an increase in mineralisation has been reported for oak, Douglas fir and Scots pine stands in the Netherlands [13]. In contrast, increased net N mineralisation without an increase in the proportion of N nitrified was reported for a sandy Scots pine soil [3]. Kreutzer [21] also found increased nitrification, but located in the mineral layer and linked to increased mineralisation. However, it has to be kept in mind that these results apply 6 months after liming, and could change in the long term. In particular, future samplings will determine whether a delayed response in the potential nitrification to the liming treatment occurs in the *P. abies* stand.

The increase in nitrification indicated the presence of acid-sensitive chemolithotrophic bacteria in both layers of the *Quercus* soil. We cannot exclude the possibility of acid-sensitive nitrification in the *Picea* soil, because the pH increase due to liming was relatively low, and until now restricted to the top 3 cm of the organic layer (L. Ruess, personal communication). However, the decrease in net NO_3^--N production in the mineral layer indicated that different N cycling processes and strategies might operate in the *Picea* soil. A watershed liming experiment (*Picea*, 3 T·ha^{-1} dolomite) also showed no effect on soil solution and stream water NO_3 concentrations, despite a pH increase in the upper layer soil solution [10].

Sufficient N supply, the presence of a mor humus, a C/N ratio (Oh) below 28 and aeration have been cited as factors favouring increased NO_3^--N losses following liming [21]. Belkacem and Nys [4] compared responses to lime of mull (oak) and moder humus (spruce) types, and reported a relatively higher increase in nitrification in the mull humus. Soils used in our study both had a moder humus, but the organic layer was thinner in the *Quercus* soil. This could indicate better nutrient cycling conditions, as also suggested by higher nutrient concentrations and pH before liming. Similarly, tree density in the field is more than double in the *Picea* stand [14], possibly leading to different temperature and moisture conditions with different bacterial populations. Furthermore, it should be noted that we measured net fluxes, possibly resulting from changes in microbial N assimilation [32].

Potential N mineralisation rates were of the same order of magnitude in both soils, but under control conditions, net nitrification was higher in the *Picea* stand. This and the different responses to lime could indicate nitrification to be acid-sensitive in the *Quercus* stand and acidophilic in the mineral soil of the *Picea* stand. Even if the bulk soil pH was unchanged in this layer, microsite conditions might already have been modified by the liming operation. Differences in acid sensitivity of nitrifiers in litter or humus layers have been reported by De Boer et al. [12]. Further analysis of the organisms responsible for nitrification in these soils and their ecological requirements would lead to improving our understanding of the nitrification process in acid forest soils.

Under control conditions, annual potential net nitrification was highest in the organic layer of the *Picea* soil, where it reached 126 kg·ha^{-1}·year^{-1} NO_3^--N; however, variability among plots from the same stand was high (*table II*). In the organic layer of the *Quercus* soil, production was only 16 kg·ha^{-1}·year^{-1} NO_3^--N. In both stands, net NO_3^--N production was lower in the mineral layer. Liming significantly increased net NO_3^--N production in the organomineral layers from the *Quercus* plot. Reduced NH_4^+-N production ($P < 0.1$) was observed in the organic layer of *Quercus* soil, and increased NH_4^+-N production in the mineral layer of the *Picea* soil.

3.3. Ground vegetation

A rapid reaction of the herb layer to liming was observed, essentially under Norway spruce. As shown in *tables III* and *IV*, 1 year after treatment the species diversity increased in limed plots, owing to the emergence of seedlings belonging to pioneer species (*Salix caprea*, *Senecio sylvaticus*), or light and N-demanding ruderals (*Epilobium angustifolium*, *Taraxacum* sp., *Epilobium*

Table II. Annual potential net N transformations (kg·ha^{-1}·year^{-1}, mean ± standard error of the mean) in the organic (org.) and mineral (min.) layers in *Quercus* and *Picea* plots, calculated from a 60-d incubation 6 months after liming.

		Quercus org.	*Quercus* min.	*Picea* org.	*Picea* min.
NO_3^--N	control	16 ± 14	5 ± 2	126 ± 44	31 ± 12
	limed	112 ± 72*	36 ± 23*	107 ± 59	35 ± 19
NH_4^+-N	control	170 ± 42	83 ± 16	110 ± 65	14 ± 12
	limed	108 ± 64#	95 ± 45	78 ± 72	62 ± 51#
Nmin	control	186 ± 53	88 ± 16	235 ± 70	45 ± 21
	limed	220 ± 37	131 ± 29*	186 ± 69	97 ± 56#

* $P < 0.05$; # $P < 0.1$. Nmin: total mineral N.

Table III. Relevés of vascular plants in 1997 in the *Quercus* stand (releve size: 169 m^2).

	Limed plots (April 1996)						Control plots					
	5	120	148	69	188	108	26	33	46	135	169	88
Tree layer covering (%)	55	85	55	80	85	65	80	70	85	85	80	80
Herb layer covering (%)	85	85	85	60	75	90	65	60	80	80	80	80
Moss layer covering (%)	< 5	< 5	5	15	5	< 5	5	10	5	< 5	10	5
Trees												
Quercus petraea	3	5	4	4	5	4	4	4	5	4	5	5
Betula alba	2		1						1	2		
Fagus sylvatica		2		2	1		3	2				
Tree seedlings												
Quercus petraea	+	+	1	1	1	1	+	1	1	1	+	1
Fagus sylvatica		1			1		+	1				
Picea abies		+	+	1	+	+	+	+		+	+	
Betula alba				+		+						
Sorbus aucuparia							+					
Salix caprea	+	+	+	+	+							
Vascular herbaceous plants												
Molinia caerulea	4	4	5	3	4	5	3	4	4	4	3	4
Pteridium aquilinum	4	1	4	3	3	3	2	2	4	3	4	3
Deschampsia flexuosa	1	2	1	2	1	1	1	2	2	1	1	2
Vaccinium myrtillus	+	+	1	1	1	1	1	1	+			1
Carex pilulifera	+	1	+	1	1		1	+			+	
Trientalis europaea						1						
Luzula luzuloïdes		1					+					
Juncus effusus						+						
Agrostis canina					1							
Galium saxatile				+								
Calluna vulgaris			+									
Holcus mollis		+										
Taraxacum sp.				+	+	1						
Senecio sylvaticus						+						
Epilobium angustifolium		+			+							
Epilobium montanum				+	+							

montanum, Urtica dioica, Cerastium fontanum subsp. *vulgare, Stellaria media*). Several (*S. capraea, Taraxacum* sp., *E. angustifolium*) had already appeared in spruce plots in great numbers in summer 1996, only a few months after treatment (*figures 3* and *4*), demonstrating a great capacity to respond to soil disturbances. This colonisation of limed plots by nitrophilic species has also been observed some years after treatment [27] as well as in a long-term survey [19]. The reaction in oak plots was less spectacular, owing to a greater competition for new seedlings by *M. caerulea* and *P. aquilinum*, and a quite thick layer of non-decayed and stratified litter, unfavourable to the emergence of young shoots.

In both stands, the initial vascular vegetation did not seem to be affected during the 2 years following the treatment. The dominant species, *M. caerulea, P. aquilinum, D. flexuosa, V. myrtillus* and *C. pilulifera,* did not show any sign of extension or regression. The apparent difference for some species, such as *D. flexuosa*, between limed and control plots (see *table IV*), was not due to treatment, but to an original heterogeneity between plots, as proved by pretreatment observations (not presented here). A previous liming experiment with Ca and Mg also showed no influence on the behaviour of *Molinia* and *Pteridium* [33]. Further quantitative observations should give us more information during the coming years.

Concerning the moss layer, the dominant species under the spruce cover, essentially *Dicranaceae*, were largely affected by the treatment (*table V*). The frequency of *Campylopus flexuosus, Dicranum montanum, Dicranella heteromalla,* for example, was clearly

Table IV. Relevés of vascular plants in 1997 in the *Picea* stand (releve size: 169 m^2).

	Limed plots (April 1996)						Control plots					
	33	3	18	36	22	23	14	41	9	19	5	31
Tree layer covering (%)	65	80	75	55	70	80	85	80	60	70	60	40
Herb layer covering (%)	10	5	10	20	30	10	10	60	20	25	25	20
Moss layer covering (%)	10	< 5	15	5	10	< 5	10	15	20	25	40	20
Trees												
Picea abies	4	5	5	4	4	3	5	5	4	4	4	3
Fagus sylvatica		2		2		2	1					
Tree seedlings												
Picea abies	2	1	2	2	2	2	1	1	2	1	2	1
Fagus sylvatica	+				+	1	+		+	+		
Quercus petraea	+									+		
Betula alba	1	+			+						+	
Sorbus aucuparia			1	+	+	+			+	+		+
Pseudotsuga menziesii		+			+							
Salix caprea	1	1	1	1	1	1						
Vascular herbaceous plants												
Vaccinium myrtillus	1	1	1	1	2	1	2	1	1	2	2	+
Dryopteris carthusiana	1	+	1	1	2	1	1		1	1	1	1
Molinia caerula	1		1	1	1	1		3	1	1	1	1
Deschampsia flexuosa				2	2		1	2	2	2	1	2
Carex pilulifera	1		1							1		1
Galium saxatile					1				1			1
Juncus effusus	+									+		1
Pteridium aquilinum				1				2				
Carex echinata				1					1			
Carex binervis	1											
Calluna vulgaris	+											1
Luzula luzuloïdes	1								1			
Luzula multiflora subsp. *multiflora*				+								
Carex canescens										+		
Agrostis canina	1	+							1			
Agrostis capillaris	1		1	1	1	+			1			
Luzula pilosa	1			1								
Trientalis europaea				1								
Taraxacum sp.	+	+	1	+	1	+						+
Senecio sylvaticus	+	+	+	+	+	+						
Epilobium angustifolium	+		+	1	1	+						
Epilobium montanum	+			+	+	+						
Sonchus cf. oleraceus	+		+		+							
Stellaria media		+			1							
Urtica dioica	+				+							
Cerastium fontanum subsp. *vulgare*			+		+							
Stellaria alsine				+								
Mycelis vulgaris					+							
Holcus mollis			+									
Ranunculus sp.			+									

reduced. At the same time, we noted the emergence or the extension of fewer acidophilous species (*Brachythecium rutabulum*, *Eurhynchium praelongum*) or ruderals, to a minor degree (*Ceratodon purpureus*, *Funaria hygrometrica*, *Bryum argenteum*, *Bryum rubens*). It is interesting to note that these species also

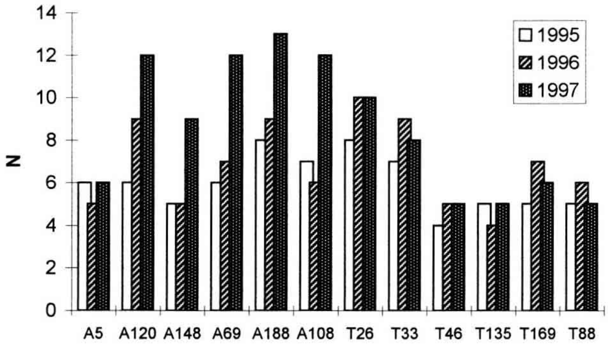

Figure 3. Number of vascular species during the period 1995–1997 in the herb layer of six plots limed in early spring 1996 (A) and six unlimed plots (T) in *Quercus* stand (releve size: 169 m^2).

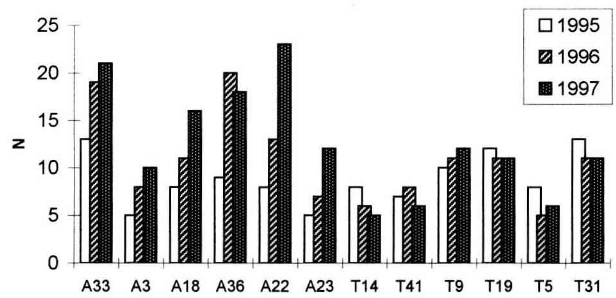

Figure 4. Number of vascular species during the period 1995–1997 in the herb layer of six plots limed in early spring 1996 (A) and six unlimed plots (T) in a *Picea* stand (releve size: 169 m^2).

Table V. Relevés of ground bryophytes in 1997.

	Quercus												*Picea*											
	Limed plots (April 1996)						Control plots						Limed plots (April 1996)						Control plots					
	5	120	148	69	188	108	26	33	46	135	169	88	33	3	18	36	22	23	14	41	9	19	5	31
Campylopus flexuosus			1			1	1	2		1	1	1	2	1					1	3	4	5	5	4
Dicranum montanum		1	1		1		2	1	2	1	1	1	1	1					2	2	2	2	2	2
Dicranella heteromalla		1			1		1	1	1		1	1				1			1	1	2	1	1	1
Campylopus pyriformis		1			1			1		1	1	1		1		1				1	1	1	1	2
Plagiothecium curvifolium					1			1	1		1						1			1	1	2	1	2
Leucobryum glaucum				1	1			1	1		1	1											1	
Lepidozia reptans					1														1		1	1	3	
Orthodontium lineare																			1	1	1	1		
Brachythecium rutabulum		1	1	1	1			1					2	1	1	1	1		1				1	1
Hypnum cupressiforme		1		1	1			1		1			2	2	1	1	2	1		1		1		
Eurhynchium praelongum													1				1	1						
Ceratodon purpureus		1			1								1			1								
Funaria hygrometrica		1		1	1																			
Bryum argenteum		1																						
Bryum rubens		1																						
Lophocolea heterophylla		1			1	1	1	1	1	1	1		2	3	2	1	3	2	2	3	2	2	2	1
Polytrichum formosum				1	1	1	1	1	1			1	3		1	1	1	1	1	1	1	2	1	2
Lophocolea bidentata					1	1								1	1		1			1	1	1		1
Mnium hornum		1		1		1							1		1		1		1			1		1
Dicranodontium denudatum													1							1		1	1	
Tetraphis pellucida							1	1											1				1	
Pohlia nutans			1		1	1																	1	
Dicranum scoparium			1				1						1											
Calypogeia muelleriana																							1	
Calypogeia sphagnicola					1	1																		
Isopterygium elegans								1											1					
Plagiothecium undulatum													1							1				

cover the areas that have been used to clean the material after the liming operation, and therefore are improved in dolomite. The behaviour of the other species could not be clearly deduced from these first investigations, which still agrees with a mid-term survey in similar conditions [1]. We can therefore expect that the immediate reaction of mosses will still be more pronounced in the coming years. Moreover, although the global number of bryophyte species was not significantly altered, their ground coverage decreased, with the decline of the most abundant species. This is particularly evident in the *Picea* stand, where the moss layer was important.

4. Conclusion

First results, 6–18 months after treatment, demonstrated a difference in the impact of dolomite lime on adjacent spruce and oak plots on acid-brown soils with quite similar chemical soil characteristics. Whereas pH and potential nitrification were mostly affected in the oak stand, herbs and mosses were particularly influenced in the spruce stand. Potential net nitrate production and pH were increased up to 15 cm in depth in the oak plots. In the spruce plots, pH only increased in the upper layer and net nitrate production decreased ($P < 0.1$) in the organomineral horizon. The appearance of N-demanding herbs and less acidophilous mosses in the spruce stand, however, indicated that changes in the biogeochemical cycling might have been caused by the dolomite lime treatment. Results so far demonstrated the immediate impact of forestry management practices not only on soil chemistry but also on the non-woody forest ecosystem components. Future data will show the relevance of our results for long-term effects, in particular whether the different impact of lime in the two ecosystems will be exacerbated or disappear.

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References

[1] Ahrens M., Einflub der Waldkalkung auf die Moosflora und die Moosvegetation des Nordschwarzwalds, Veröff. Naturschutz Landschaftspflege Bad.-Württ. 70 (1995) 455–496.

[2] Allen S.E., Chemical Analysis of Ecological Materials, Blackwell, Oxford, 1989.

[3] Arnold G., van Beusichem M.L., van Diest A., Nitrogen mineralisation and H^+ transfers in a Scots pine (*Pinus sylvestris* L.) forest soil as affected by liming, Plant Soil 161 (1994) 209–218.

[4] Belkacem S., Nys C., Consequences of liming and gypsum top-dressing on nitrogen and carbon dynamics in acid forest soils with different humus forms, Plant Soil 173 (1995) 79–88.

[5] Belkacem S., Nys C., Gelhaye D., Effet d'une fertilisation et d'un amendement sur l'immobilisation d'éléments dans la biomasse d'un peuplement adulte d'épicea commun (*Picea abies* L. Karst), Ann. Sci. For. 49 (1992) 235–252.

[6] Bonneau M., Sessile oak seedling fertilization and leaf mineral composition in western France, Ann. Sci. For. 53 (1996) 605–613.

[7] Bonneau M., Landmann G., Garbaye J., Ranger J., Nys, C., Gestion et restauration de la fertilité minérale des sols, Rev. For. Fr. 46 (1994) 579–585.

[8] Bremner J.M., Inorganic forms of nitrogen, in: Black C.A., Evans D.D., Ensminger L.E., White J.L., Clark F.E., Dinova R.C. (Eds.), Methods of Soil Analysis, Pt. 2, Chemical and Microbiological Properties, American Society of Agronomy, Madison, WI, 1965, pp. 1179–1237.

[9] Carnol M., Etude de l'influence des facteurs du milieu sur la nitrification dans l'horizon holorganique d'une pessière, mémoire de licence, Université de Liège, Belgium, 1991.

[10] Carnol M., Piret A., Requier M.-C., Remacle J., Amendement de bassins versants dans les Ardennes belges: effets sur l'eau de percolation et l'eau à l'exutoire, in: Santé de la forêt wallonne, 1999 (in press).

[11] Claes V., Influence des facteurs mésologiques sur le dépérissement des chênes indigènes (*Quercus robur* L. et *Quercus petraea* (Mattuscka) Lieblein) en Région Wallonne, mémoire de DEA, Gembloux, Belgium, 1998.

[12] De Boer W., Tietema A., Klein Gunnewiek P.J.A., Laanbroek H.J., The chemolithotrophic ammonium-oxidizing community in a nitrogen-saturated acid forest soil in relation to pH-dependent nitrifying activity, Soil Biol. Biochem. 24 (1992) 229–234.

[13] De Boer W., Hundscheid M.P.J., Schotman J.M.T., Troelstra S.R., Laanbroek H.J., In situ net N transformations in pine, fir, and oak stands of different ages on acid sandy soil, 3 years after liming, Biol. Fert. Soils 15 (1993) 120–126.

[14] Dulière J.-F., Travaux préliminaire à l'évaluation de la réaction d'écosystèmes forestiers (chênaie et pessière) à des perturbations d'origine anthropique (amendements) en Haute Ardenne: impact sur la phytocénose et la mycocénose, y compris les ectomycorhizes, mémoire de D.E.A., Faculté universitaire des sciences agronomiques, Gembloux, Belgium, 1996.

[15] Dulière J.-F., Malaisse F., Le point sur le dépérissement du chêne – les progrès récents de la recherche, Forêt Wallonne 22 (1995) 17–19.

[16] Durand P., Gelpe J., Lemoine B., Riom J., Timbal, J., Le dépérissement du chêne pédonculé dans les Pyrénées-Atlantiques, Rev. For. Fr. 35 (1983) 357–368.

[17] Giot P., Malaisse F., Duran V., Thierron V., Claes V., Misson L., André P., Dulière J.-F., Penninckx V., Meerts P., Herbauts J., Gruber W., Dossier: la forêt sous haute surveillance, Forêt Wallonne 30 (1997) 3–21.

[18] Huettl R.F., Fink S., Lutz H.-J., Poth M., Wisniewski J., Forest decline, nutrient supply and diagnostic fertilization in southwestern Germany and southern California, For. Ecol. Manage. 30 (1990) 341–350.

[19] Immer A., Schmidt W., Meiwes K.J., Beese F., Langzeitwirkungen von Kalkung und Düngung auf den chemischen Zustand im Oberboden, die Humusformen und die Bodenvegetation in einem Fichtenforst, Forstwiss. Centralbl. 112 (1993) 334–346.

[20] Kölling C., Pauli B., Häberle K.-H., Rehfuess K.E., Magnesium deficiency in young Norway spruce (*Picea abies* (L.) Karst.) trees induced by NH_4NO_3 application, Plant Soil 195 (1997) 283–291.

[21] Kreutzer K., Effects of forest liming on soil processes, Plant Soil 168/169 (1995) 447–470.

[22] Mueller-Dombois D., Ellenberg H., Aims and Methods of Vegetation Ecology, John Wiley & Sons, New York, 1974.

[23] Nageleissen L.-M., Dépérissement actuel des chênes, Rev. For. Fr. 46 (1994) 504–511.

[24] Noirfalise A., Forêts et station forestières de Belgique, Les presses agronomiques de Gembloux, Belgium, 1984.

[25] Nys C., Fertilisation, dépérissement et production de l'épicea commun (*Picea abies*) dans les Ardennes, Rev. For. Fr. 41 (1989) 336–347.

[26] Nys C., Amendements: éléments de stabilité du fonctionnement de l'écosystème forestier, Silva Belgica 102 (1995) 13–18.

[27] Picard J.-F., Becker M., Lebourgeois F., Modifications de la flore et de l'humus induites par un apport de calcium dans différents écosystèmes forestiers du nord-est de la France, in: Nys C. (éd.), Forêts et amendements calcaires, Inra, Champenoux, 1993, pp. 61–73.

[28] Ranger J., Mohamed Ahamed D., Gelhaye D., Effet d'un amendement calco-magnésien associé ou non à une fertilisation sur le cycle biogéochimique des éléments nutritifs dans une plantation d'épicea commun (*Picea abies* Karst) dépérissante dans les Vosges, Ann. Sci. For. 51 (1994) 455–475.

[29] Rodenkirchen H., Auswirkungen von saurer Beregnung und Kalkung auf die Vitalität, Artenmachtigkeit und Nährstoffversorgung der Bodenvegetation eines Fichtenbestandes, Forstwiss. Centralbl. 105 (1986) 338–350.

[30] SAS Institute Inc., SAS/Stat User's Guide, Version 6, Vol. 1, Cary, NC, USA, 1989.

[31] Sougnez N., Weissen F., Evolution de la couverture morte et de la couverture vivante après fumure en vieille forêt d'épicea commun, Bulletin des recherches agronomiques de Gembloux 12 (1977) 233–248.

[32] Stark J.M., Hart S.C., High rates of nitrification and nitrate turnover in undisturbed coniferous forests, Nature 385 (1997) 61–64.

[33] Trichet P., Gelpe J., La fertilisation peut induire des substitutions de flore et modifier la réussite des plantations, Rev. For. Fr. 49 (1992) 35–42.

[34] Weissen F., Dix ans plus tard: l'état de la question sur le dépérissement en forêt wallonne, Silva Belgica 103 (1996) 9–19.

[35] Weissen F., Van Praag H.J., Maréchal P., Delecour F., Farcy Ch., Les causes de la dégradation sanitaire des forêts en Wallonie: le point de la situation, Bull. Soc. Roy. For. 95 (1988) 57–68.

[36] Weissen F., Hambuckers A., Van Praag H.J., Remacle J., A decennial control of N-cycle in the Belgian Ardenne forest ecosystems, Plant Soil 128 (1990) 59–66.