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ORIGINAL ARTICLE

Effect of soil liming on European beech (*Fagus sylvatica* L.) and sycamore maple (*Acer pseudoplatanus* L.) plantations

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Abstract

Support of European beech (*Fagus sylvatica* L.) and sycamore maple (*Acer pseudoplatanus* L.) plantations by amelioration has been tested in air-polluted sites in the mountains since 1993. The research locality is a site with humic podzol soils at an altitude of 960 m a.s.l. Dolomitic limestone (1 kg per tree) was mixed with soil used for planting tree seedlings. According to the results of a 15-year investigation (1993–2008), liming had a positive effect on beech tree growth, while the positive effect of liming on tree growth was temporary in the case of sycamores. Ca content was higher in the limed beech plantations throughout the observation period. Soil analyses (sampled in 2002) showed that the application of dolomitic limestone influenced soil conditions markedly in terms of increased pH. The pH values measured in H_2O increased from 4.9 to 6.2 for beeches and from 4.3 to 6.1 for sycamores.

Keywords

Acer pseudoplatanus, Fagus sylvatica, forest decline, North Bohemia, soil amelioration

Introduction

The substantial forest decline in the Jizera Mountains (North Bohemia) observed during the period of just about 1975–1995 is common knowledge (Borůvka et al. 2007). Nearly 12,000 ha of forests were affected by air pollution load (sulphur dioxide) arisen from industrial enterprises, chiefly thermal power stations. Mountain forests within a large area on both the Czech and Polish sides of the Sudeten Mountains were severely damaged. Both the wood-production and non-production ecological forest functions (e.g. hydrologic functions, soil protection, etc.) were disturbed and forestry practice faced a new and serious task of restoring forest within large open areas. The mountain forests had to be restored using tree species with higher tolerance to pollution stress which did not show signs of physiological damage (see Nebe 1997) under altered environmental conditions. Inasmuch as such species are also climax species, this is adequate also for its potential to provide natural vegetation.

As important broadleaved target tree species for restoration of mountain forest stands, the European beech (*Fagus sylvatica* L.) and the sycamore maple (*Acer pseudoplatanus* L.) were planted for testing in our experimental plot. Besides wood production, these broadleaved tree species are expected to fulfil stand-stabilizing and soil-

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improving functions. The sycamore, for example, is cited as a minor but widespread species which has potentially high economic and ecological values (Hein et al. 2009). In the Jizera Mountains, sycamore and beech species are naturally distributed up to the mountain ridges, i.e. even on sites situated above 900 m a.s.l. Because young beech and sycamore trees are sensitive to climatic stress as well as biotic pests, and therefore can be prone to failure, a liming treatment of acidic soil environment was applied to strengthen these tree species vigour at the critical juvenile stage of their development. Liming of forest soil has been an important measure to prevent soil acidification and increase base saturation since the early 1980s (Schaaf and Hüttl 2006) as well as has been cited as a therapeutic measure (Nebe et al. 1997) under the conditions an air-polluted environment. The aim of our study was to assess the ameliorative effect of liming on young beech and sycamore trees and on certain nutrient contents and soil parameters in the course of the first 15 years after application.

MATERIALS AND METHODS

The study site represents localities found on mountain ridges at an elevation of about 1,000 m a.s.l. (Balcar and Podrázský 1994). The altitude of the sites (50° 49′ 34″ N, 15° 21′ 19″ E) is nearly 960 m a.s.l. The type of forest in the area was classified as acidic spruce [*Picea abies* (L.) Karst.] forest with reed grass [*Calamagrostis villosa* (Chaix) J.F. Gmelin], while soil type was classified as the mountain humic podzol (FAO 1988). The soil texture is derived from biotitic granite.

According to climate monitoring results (1996–2007), mean air temperature at the site is 5.1°C and mean annual precipitation is 1,093 mm (Slodičák et al. 2005; Balcar and Kacálek 2008).

The plantations were established in May 1993. Two-year-old bare-rooted transplants of both observed tree species (beech and sycamore) were planted into planting holes (35 × 35 × 25 cm) at the spacing of 2 × 1 m within square subplots 10 × 10 m in size (50 trees per subplot, i.e. 5,000 trees per ha). For both species, there were two control replications (subplots) and two limed ones (the distance between replications was about 30 m). All plantations were fenced in to be protected against damage from deer (*Cervus elaphus* L.) and hares (*Lepus europaeus* Pallas).

Lime was applied at the same time as planting, and 1 kg per tree of finely ground dolomitic limestone was mixed with soil in each planting hole. This patch-wise approach to incorporating limestone into mineral soil is called spot liming (Pampe et al. 2004). Limestone contained 21.5% Ca and 11.25% Mg. Described granulometrically, the material consisted of 5.8% particles with the diameter larger than 1 mm, 16.3% particles 0.5–1 mm, 20.4% particles 0.2–0.5 mm, and 57.5% particles with the diameter smaller than 0.2 mm (Balcar and Podrázský 1995). Prevailing fine particles are an important factor in terms of the efficiency of neutralizing treatment (Strojny 1992).

The health of observed plantations (injury symptoms and mortality rate) was investigated annually in spring after flushing of shoots (May–June). Dead and damaged trees (due to injuries caused by voles (*Microtus agrestis* L.), spring frosts, snow layer and other harmful factors) were visually evaluated and counted as a portion (%) of the total number of trees (100% = all planted trees). The second regular health condition assessment and height measurement of all trees was conducted at the beginning of autumn. Because of frequent mortality and damage to the tested beech and sycamore transplants, the liming effect on beech and sycamore plantation vitality was assessed on a basis of the cumulative height of 10 highest trees living in 2008 (10 trees per subplot, which was 20% of the initial number of planted trees). Using the height of dominant trees helps to avoid misinterpretation caused by presence of individuals in decline. The heights of individual trees were logarithmically transformed. In order to avoid pseudoreplication (Hurlbert 1984), mean values of heights for individual plots were calculated for subsequent analyses. ANOVA for repeated measurements was performed. We chose this analysis because we were interested in how the effects of treatments would vary in time. In order to substantiate different patterns in height development between treatments (and between species), the interactions age × treatment and age × species were tested. The statistical package R version 2.8.0 was used for statistical computing (R Development Core Team 2008).

Tree nutrition status was assessed using leaf analyses. Leaf samples were taken in late summer (1993–2008). A composite sample of leaves was taken from the upper crown of 20 trees (10 per subplot) for each experimental variant (limed and control). Samples were analysed according to the standard method (Zbíral

1994) and expressed as a percentage of macroelements (N, P, K, Ca, Mg) in dry matter of assimilatory tissues. Nutrition status of beech leaves was assessed by comparing the results obtained with the "limits of sufficient nutrition" published for beech by Vries et al. (1998). For nutrients in sycamore leaves, we used criteria published by Kopinga and van den Burg (1995).

The long-term effect of liming on soil was assessed using analyses of soil samples taken on beech and sycamore subplots in 2002. Soil analyses were performed on composite soil samples the following procedure. Approximately 15 cores were taken within each treatment variant. A core is a subsample of soil taken with a soil corer (3 cm inside diameter) from the area of a planting hole. Subsamples from a given treatment variant were mixed together and analysed. Since the finest roots are located in the surface layer (0 to 20 cm), the soil samples were collected from this zone. The following chemical properties of the soil were determined: pH measured in water and KCl and soil adsorption complex characteristics according to Kappen (1929), i.e.: base content, hydrolytic acidity, cation exchange capacity, base saturation, total carbon and nitrogen (Kjeldahl), C/N ratio, and the content of plant-available nutrients in 1% citric acid solution. Plant-available P2O5 was determined using the Specol 210 apparatus (Carl Zeiss, Jena, Germany), plant-available K_2O – by flame photometry, and CaO and MgO content – by atomic absorption spectrometry.

RESULTS

During the 15-year (1993–2008) observation the European beech showed a high mortality rate, with the average of total plantation mortality reaching 57% (Tab. 1). In the control plantations the mortality rate was markedly lower than that of limed treatment (48% and 67%, respectively). The majority of losses occurred during the first 4 years after planting, and the main causes were damage by voles (*Microtus agrestis*, 12%) and climatic stress (spring frosts and the like, 25%). The highest injury caused due to spring frosts appeared in mid-May 2000. Nearly 89% of living in the year 2000 beech trees (subsequent mortality 5%) and 64% of sycamore trees (mortality 1%) exhibited leaf necrosis that occurred nearly up to 1 m above the soil surface. No obvious difference between frequency of injury in limed and control plantations was observed in either species.

The final differences between the limed and control plantations were 38% and 42%, respectively. The same damage was identified for sycamores as for beeches. The mortality rate during the first 4 years after planting due to damage by voles was 7%, while due to other factors it was 14%.

Significant interaction between tree age and treatment shows a different pattern of height development in limed and control treatments. Significant interaction between tree age and species shows also a different height development in beech trees as compared to sycamores (Tab. 2). The principal difference is that the effect of liming was still detectable in beech plantations at the end of the observation period while liming of sycamore plantations seemed to have a temporary effect (Fig. 1).

According to the ICP-Forest criteria (Vries et al. 1998), nutrient contents (Tab. 3 and 4) in beech leaves showed long-lasting macroelement deficiency only in the case of potassium (K). The same was true also in sycamore leaves according to Kopinga and van den Burg (1995). As for other macroelements, the deficiency of nitrogen (N) and magnesium (Mg) was occasionally observed, both in the limed and control beech plantations. On the other hand, there was found nitrogen deficiency in sycamore leaves. No deficiency in beech leaves was found in calcium (Ca) and phosphorus (P).

Tab. 1. Cumulative mortality of European beech and Sycamore maple (%)

Species	Treatment	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Beech	control	2	16	25	29	31	37	40	41	45	45	46	48	48	48	48	48
Beech	liming	0	35	42	45	47	52	54	58	60	60	64	67	67	67	67	67
Sycamore	control	0	7	14	15	18	24	24	28	32	35	35	35	35	40	41	42
Sycamore	liming	1	23	26	27	28	31	33	33	35	37	38	38	38	38	38	38

Cumulative mortality = total mortality from planting (1993) to the year shown in the particular column, 100% = initial number of plantings

Tab. 2. ANOVA for repeated measurements

Error term: Plot					
	Df	Sum Sq	Mean Sq	F value	P value
Treatment	1	0.0207	0.0207	0.265	0.629
Species	1	0.1566	0.1566	1.999	0.217
Residuals	5	0.3918	0.0784		
Error term: Within					
	Df	Sum Sq	Mean Sq	F value	P value
Age	16	12.8257	0.8016	495.106	< 0.001
Age × Treatment	16	0.0551	0.0034	2.128	0.015
Age × Species	16	0.3819	0.0239	14.741	<0.001
Residuals	80	0.1295	0.0016		

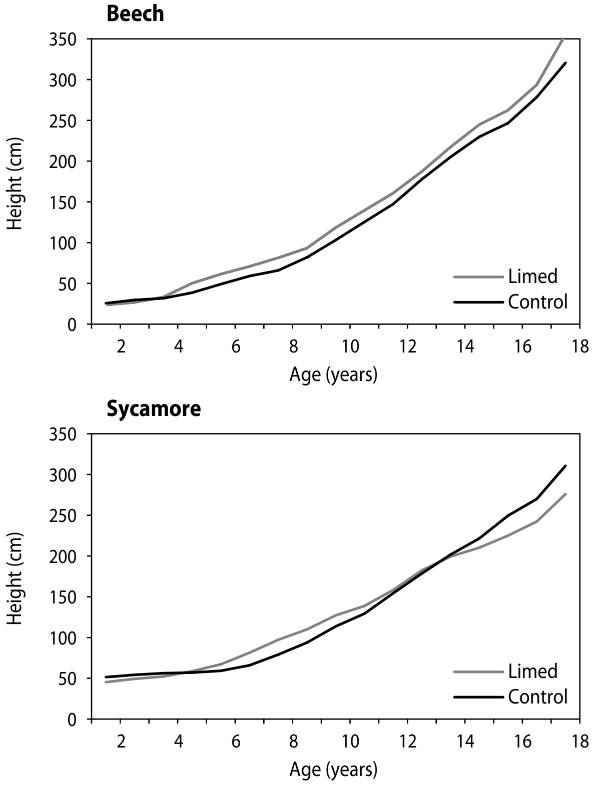

Fig. 1. Height development of dominant individuals in experimental plantations. The temporary effect of liming in sycamore is obvious

No significant increase in Mg content was observed in dry mass of leaves after liming, while the Ca content was higher in the limed beech plantations throughout the observation period (1993–2008). According to the results of soil analyses (Tab. 5), the pH values (both measured in H_2O and KCl) were also markedly higher after application of finely-ground dolomitic limestone. This treatment also reduced hydrolytic acidity and increased the contents of exchangeable bases, cation exchange capacity and base saturation. No substantial differences between the control and limed plantations were registered in terms of oxidable carbon content. Total soil nitrogen was also nearly the same in the variants. The contents of plant-available P_2O_5 and K_2O in limed soil were rather lower than those in untreated soil. On the other hand, addition of limestone increased the contents of CaO and MgO in soil. The variant differences in all the aforementioned soil parameters were similar in beech and sycamore plantations.

DISCUSSION

Rodents are cited as a factor impeding beech stand renewal as they predate seeds which were artificially sown (Birkendal et al. 2009). However, they can also damage plants by feeding on both roots and basal parts of the stem. This is the type of damage we found. Different mortality rates in the two tree species could be explained by higher attractiveness of the beech for voles, as noted by Flousek (1996), and more frequent beech damage by late frosts due to its earlier flushing in the spring.

The treatment effects upon the beech were still obvious 15 years after plantation establishment, the same as previously reported by Pampe et al. (2004) for a limed-beech trial in Germany's Harz Mountains. However, the effect of liming upon the sycamore height seems to run its course.

The positive effect of liming on young forest plantations (including those of beech) was also demonstrated in Germany, where it was recommended to add 0.5 kg of dolomitic limestone into planting holes when transplanting trees (Nebe and Leube 1995). Malek and Greszta (1996) reported increased weight and growth of beech seedlings under the influence of liming. Ceitel and Zientarski (2002) also observed positive effects of dolomite fertilization on survival and increased average height of the beech, sycamore maple, rowan, larch and spruce in formerly air-polluted Polish Sudeten Mountains. On the other hand, ambiguous effects of liming

Tab. 3. Concentration of nutrients in European beech leaves (% of dry mass)

Macroelement	N%		P%		K%		Ca%		Mg%	
Sampling/Variant	Limed	Control	Limed	Control	Limed	Control	Limed	Control	Limed	Control
1993	1.850	1.810	0.180	0.130	**0.430**	**0.380**	0.790	0.450	0.290	0.310
1995	1.745	1.680	0.260	0.200	**0.390**	**0.380**	0.590	0.460	0.090	0.120
1996	1.695	1.515	0.180	0.140	**0.320**	**0.320**	0.830	0.630	0.160	0.180
1997	1.930	1.850	0.180	0.160	**0.430**	**0.430**	0.650	0.570	0.160	0.150
1998	1.850	1.920	0.180	0.170	**0.310**	**0.340**	1.040	0.920	**0.090**	**0.090**
1999	1.618	1.622	0.170	0.170	**0.410**	**0.300**	0.600	0.550	0.130	0.120
2000	**1.434**	**1.485**	0.150	0.300	0.500	**0.300**	0.880	0.660	0.150	0.150
2001	1.820	1.850	0.240	0.210	**0.230**	**0.190**	0.740	0.690	0.200	0.200
2002	1.811	1.822	0.141	0.127	**0.435**	**0.470**	0.915	0.803	0.172	0.156
2003	1.787	1.777	0.160	0.140	0.520	0.580	0.910	0.800	0.262	0.251
2004	1.805	1.698	0.141	0.117	**0.480**	**0.480**	0.820	0.740	0.250	0.230
2005	1.685	1.676	0.137	0.128	0.520	0.560	1.470	1.270	0.173	0.167
2007	1.610	1.549	0.130	0.090	0.440	0.420	1.210	1.010	0.216	0.198
2008	1.714	1.755	0.246	0.212	0.540	0.530	0.890	0.840	0.203	0.191
Average	1.740	1.715	0.178	0.164	0.425	0.406	0.881	0.742	0.182	0.180
Sufficient nutrition	1.50–2.50		0.10–0.17		0.50–1.00		0.40–0.80		0.10–0.15	

Sufficient nutrition – lower and upper limit of leaf content for sycamore (Vries et al. 1998). Bold letters – extremely low nutrient supply

Tab 4. Concentration of nutrients in Sycamore maple leaves (% of dry mass)

Macroelement	N%		P%		K%		Ca%		Mg%	
Sampling/Variant	Limed	Control	Limed	Control	Limed	Control	Limed	Control	Limed	Control
1993	1.770	**1.585**	0.110	0.133	**0.410**	**0.515**	0.530	0.590	0.284	0.315
1995	**1.515**	**1.360**	0.245	0.158	**0.490**	**0.478**	0.975	0.618	0.355	0.275
1996	**1.235**	**1.325**	0.210	0.153	**0.485**	**0.430**	1.170	0.725	0.243	0.233
1998	**1.570**	**1.670**	0.160	0.200	**0.400**	**0.410**	1.470	1.180	0.115	0.115
1999	**1.612**	**1.464**	0.168	0.173	**0.550**	**0.370**	0.880	0.683	0.149	0.147
2000	**1.404**	**1.406**	0.124	0.105	**0.360**	**0.410**	0.820	0.710	0.260	0.227
2001	**1.440**	1.735	0.227	0.234	**0.280**	**0.270**	0.810	0.770	0.369	0.410
2002	1.726	**1.528**	0.158	0.135	**0.570**	**0.537**	1.205	1.163	0.356	0.374
2003	**1.580**	**1.534**	0.130	0.130	**0.640**	**0.620**	1.270	1.110	0.615	0.602
2004	**1.440**	**1.500**	0.124	0.118	0.710	**0.620**	0.990	1.000	0.440	0.440
2005	**1.688**	**1.582**	0.135	0.118	0.770	0.760	1.230	1.120	0.335	0.320
2007	**1.553**	**1.520**	**0.080**	**0.079**	**0.550**	**0.480**	1.140	1.150	0.450	0.304
2008	**1.448**	**1.246**	0.275	0.192	**0.660**	**0.470**	1.040	1.040	0.404	0.411
Average	1.544	1.517	0.163	0.151	0.515	0.493	1.032	0.879	0.320	0.314
Sufficient nutrition	2.3–2.7		0.16–0.22		1.15–1.50		–		0.17–0.27	

Sufficient nutrition – lower and upper limit of leaf content for sycamore (Kopinga and van den Burg 1995). Bold letters – extremely low nutrient supply

Tab. 5. Soil chemistry in planting holes of tested trees 9 years after planting (sampled in 2002)

Sampling	Unit	Beech		Sycamore	
Treatment variant		Control	Liming	Control	Liming
pH/H_2O	–	4.9	6.2	4.3	6.1
pH/KCI	–	3.7	5.4	3.8	5.0
Base content	mval/100g	3.4	48.4	5.6	47.9
Hydrolytic acidity	mval/100g	10.3	2.7	13.7	1.0
Cation exchange capacity	mval/100g	13.7	51.2	19.3	48.9
Base saturation	%	24.9	94.7	28.9	98.0
Total carbon	%	3.7	4.0	5.9	5.2
Total nitrogen	%	0.2	0.2	0.4	0.3
C/N ratio	–	18.5	20.0	14.6	17.2
P_2O_5 content	mg/kg	9.6	2.3	15.1	12.0
K_2O content	mg/kg	5.9	3.5	8.5	3.5
CaO content	mg/kg	50.7	2,166.7	94.7	3,000.0
MgO content	mg/kg	16.6	51.3	35.3	62.0

were documented by Podrázský and Remeš (2004). They found that beech under-plantings treated with 1 kg of crushed limestone per tree showed better height growth, even as limed plantations on the clear-cut area grew without difference compared to the control treatments. We found the opposite trend between limed and untreated sycamores, as the control was significantly higher in 2008.

Regarding foliar nutrient contents, Podrázský and Remeš (2004) noted a great increase in Ca and no marked response in the concentrations of other macroelements. Increased concentrations of both Ca and Mg in beech leaves were found by Misson et al. (2001) in Belgian Ardennes after application of dolomite and by Nebe et al. (1996) in the Ore Mountains, Germany. Other tree species responded to the addition of limestone in terms of significantly increased calcium concentration in assimilating organs, as reported by Rosberg et al. (2006) for the Scots pine in Norway and Šrámek et al. (2006) for the Norway spruce in the Ore Mountains, Czech Republic.

Liming is considered an appropriate measure to ameliorate forest soils in order to prevent further soil acidification and to increase either pH or base saturation level (Nebe et al. 1996; Geissen et al. 2003; Erstad 2006; Schaaf and Hüttl 2006; Szoltyk 2006; Saarsalmi and Levula 2007).

Zirlewagen and von Wilpert (2004) also reported increased base saturation when dust particles in applied limestone prevailed as compared to using material containing more coarse particles.

Geissen et al. (2003) also found a similar trend of lower P and increased Ca and Mg for a dolomite-treated site.

Except for exchangeable P, Kuneš (2003) described similar results of liming on soil chemistry obtained during experiments on Norway spruce amelioration which were situated in close vicinity to our experimental plantations.

CONCLUSIONS

Finely ground dolomitic limestone applied into planting holes influenced the height of European beech (*Fagus sylvatica*) while Sycamore maple (*Acer pseudoplatanus*) plantations did not respond to the addition of limestone in the same way.

Nutrient content in beech and sycamore leaves was not influenced by liming, with the exception of increased calcium content in limed plantations as compared to untreated ones.

The application of dolomitic limestone markedly influenced soil conditions in terms of increased pH.

We consider issues related to the initial support of broadleaved trees with the use of chemical amelioration to be highly relevant in the harsh conditions of air-polluted mountains. Despite relatively long-term series of data obtained, further field investigation of chemical amelioration is needed. Finding appropriate possibilities to restore sustainable and multifunctional forest ecosystems remain crucial in the area of the formerly air-polluted Jizera Mountains.

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