Influence of a planting hole application of dolomitic limestone powder and basalt grit on the growth of Carpathian birch (*Betula carpatica* W. et K.) and soil chemistry in the air-polluted Jizerské hory Mts.

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ABSTRACT: The objective of the study was to evaluate the growth potential of Carpathian birch (*Betula carpatica* W. et K.) at an environmentally harsh mountain site and a response of this species to altered soil chemistry after dolomitic limestone and basalt grit applications. The Carpathian birch proved to be a suitable species for the replanting of extreme acidic mountain sites. This birch shows a low mortality rate, grows well in the clear-felled patches and soon forms a cover which is necessary for the reintroducing of more sensitive tree species. The application of dolomitic limestone and basalt grit resulted in the slower growth of Carpathian birch plantations. Liming raised soil reaction, sum of exchangeable bases, base saturation, cation exchange capacity and reduced exchangeable Al content. On the other hand, liming decreased an amount of oxidizable soil organic matter and negatively affected soil N, exchangeable P and K. Basalt grit increased exchangeable P and K contents and raised soil reaction, however only slightly. The influence of basalt grit on the sum of exchangeable bases, base saturation and cation exchange capacity was also less pronounced compared to liming. Basalt grit elevated the proportion of exchangeable aluminium and reduced the content of soil N.

Keywords: Carpathian birch (*Betula carpatica* W. et K.); Jizerské hory Mts.; chemical amelioration; liming; basalt grit; forest soils; acidic deposition; forest ecosystems

Forest ecosystems in the Jizerské hory Mts. (Northern Bohemia) were heavily affected by air pollution stress followed by tortrix (*Zeiraphera griseana* Hbn.) and bark beetle (*Ips* ssp.) outbreaks (Vacek et al. 2003). Therefore, large areas of forest stands had to be cut down in the 1980s. In terms of air pollution, the situation improved substantially in the 1990s, however, it is still very difficult to replant the clear-felled patches mainly because of their harsh microclimate. Carpathian birch (*Betula carpatica* W. et K.) as an autochthonous pioneer species might play an important role in the process of restoration of forests damaged or destroyed by air pollution.

Despite some morphological and taxonomic problems regarding Carpathian birch (Úradníček et al. 2001), this taxon is prevailingly considered as a narrowly defined species in recent Czech literature (Kříž 1990; Kubát 2002). There is however a lack of detailed information regarding the ecological requirements of this species that naturally occurs in the Central European mountains on poor acidic soils. To counteract the process of soil acidification caused by deposition of air pollutants, liming and

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application of basic amendments is used in some cases. The objective of this study is to evaluate the response of Carpathian birch, which presumably requires an acidic soil environment, to precisely applied dolomitic limestone and basalt grit.

MATERIALS AND METHODS

The planting experiment was installed in the framework of the Jizerka Field Experiment managed by the Opočno Research Station (Forestry and Game Management Research Institute in Jíloviště-Strnady) on the Central Ridge of the Jizerské hory Mts. (Střední Jizerský hřeben – latitude 50°49´N, longitude 15°21´E, Northern Bohemia) at an altitude of 980 m. The experimental plantation is located on a large clear-felled patch on the summit of the ridge. The mean annual air temperature (1996–2003) at the site is 4.9°C and the mean annual precipitation (1994–2003) is 1,089 mm (Balcar in Slodičák et al. 2005). The bedrock is biotitic granite. The soil was determined as a transition form from mountain humus podzol to peat podzol (Umbri Placic Podzol according to the FAO terminology). Stratification: L (0–2 cm), F (2–8 cm), H (8–12 cm), Ah (12–13 cm), Ep (13–17 cm), B (17+ cm). The average air SO_2 and fluorine concentration is 11 μg/m^3 and 0.18 μg/m^3.

The trees were planted on a game-proof fenced plot in the spring of 1993. The experimental plantation consists of Carpathian birch (*Betula carpatica* W. et K.) trees which originate from the Jizerské hory Mts. A 1-year-old bare-rooted planting stock was used. A block of 7 subplots was established. Each subplot (10 × 10 m) contained 50 trees at the spacing of 1 × 2 m at that time. In addition to the control variant (3 subplots), two alternative variants were established: the "limestone variant" (2 subplots) and the "basalt variant" (2 subplots).

In the limestone variant, 1 kg of the dolomitic limestone powder was incorporated into the soil within the space of planting holes (35 × 35 × 25 cm) per each tree at planting. It means that 50 kg of the amendment were used per 100 m^2.

In the basalt variant, the basalt grit was incorporated into the soil inside the planting holes. 2 kg of basalt grit per tree were used in an effort to achieve a sufficient acidity neutralizing effect.

The dolomitic limestone from the Horní Lánov quarry (Northern Bohemia) was used. This amendment contained 21.5% of Ca and 11.3% of Mg. In terms of particle-size distribution, the limestone powder consisted of 5.8% of particles over 1 mm in diameter, 16.3% of particles between 1.0 and 0.5 mm in diameter, 20.4% of particles between 0.5 and 0.2 mm in diameter and 57.2% of particles below 0.2 mm in diameter.

The applied basalt grit originated from the Nové Město pod Smrkem quarry (Northern Bohemia). The material contained 8.6% of Ca, 6.1% of Mg, 0.96% of K and 0.41% of P. In this amendment, there were 60% of particles larger than 1 mm in diameter, 19% of particles 0.5–1 mm, 13% of particles 0.5–0.2 mm in diameter and 8% of particles smaller than 0.2 mm. The particle size distribution of the applied basalt material is not optimal. The material was, however, a waste of a local quarry and there was a request for its testing as a cheap environmentally-friendly basic amendment at that time.

A scaled rod was used to measure tree height and crown diameter. The tree heights were measured to the nearest 1 cm and crown diameter to the nearest 10 cm. A calliper was used to measure the stem base diameter to the nearest ± 1 mm.

The nutrition analyses are presented in percentages of macroelements (N, P, K, Ca, Mg, S) in dry matter of assimilatory (leaf) tissues. The nutrition status of assimilatory tissues was determined in 1993, 1994, 1995, 1996, 1999, 2000, 2001, 2003 and 2004. A composite sample of leaves from each variant was taken around the turn of August and September, when the aboveground parts of the trees had finished their active growth. The healthy fully developed leaves were pooled in the samples.

Soil samples were taken in September 2002. Two composites for each variant were formed: the 0 to 10 cm composite and the 10–20 cm composite. This limited number of composites per variant was taken in order to avoid damage to the roots of the tested trees because the soil was sampled directly from the space-limited planting holes densely colonized by roots.

The composites were formed so that approximately 15 to 20 cores were taken within a particular treatment variant. A core is considered as a subsample of soil taken with a soil corer (3 cm in diameter) from the space of a planting hole. Since most feeder roots are located in the surface layer (0 to 20 cm), the soil samples were collected from this zone. The L-horizon was removed from the cores because it was usually integrated into the sod layer of grass. Each core was then divided into a 0–10 cm part and 10–20 cm part. The separated parts were pooled into the 0–10 cm and 10–20 cm composites within a particular variant. This approach of pooling small cores into bulk composites does not facilitate a statistical analysis. Though, the achieved information seems to be highly relevant.

The following chemical properties of the fine homogenized earth of the composites were deter-

Table 1. Development of total mortality (T.M.) and annual mortality (A.M.) in the particular treatment variants

Variant		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Control	T.M. (%)	0.0	3.4	7.4	10.7	11.4	12.8	12.8	13.4	14.1	14.1	14.8	14.8
	A.M. (%)	0.0	3.4	4.0	3.4	0.7	1.3	0.0	0.7	0.7	0.0	0.7	0.0
Limestone	T.M. (%)	0.0	1.0	1.0	1.0	3.1	3.1	3.1	3.1	4.1	4.1	4.1	4.1
	A.M. (%)	0.0	1.0	0.0	0.0	2.1	0.0	0.0	0.0	1.0	0.0	0.0	0.0
Basalt	T.M. (%)	0.0	0.0	2.1	4.1	8.2	8.2	10.3	11.3	12.4	12.4	13.4	13.4
	A.M. (%)	0.0	0.0	2.1	2.1	4.1	0.0	2.1	1.0	1.0	0.0	1.0	0.0

mined: pH in water and 1N KCl, characteristics of soil adsorption complex (SEB – sum of exchangeable bases, CEC – cation exchange capacity, BS – base saturation) according to Kappen's procedures, further the oxidizable organic matter (Springer-Klee), soil nitrogen content (Kjeldahl's method) and exchangeable nutrients extracted with 1% solution of citric acid. The plant available P was determined by the Spekol 210 apparatus, plant available Ca and Mg by AAS (Atomic Absorption Spectroscopy).

The samples of assimilatory tissues and soil samples were analyzed at the Tomáš Laboratory using the procedures described by Zbíral (1994, 1995, 1996).

Height increment, stem base diameter and crown diameter were statistically analyzed using the Kruskal-Wallis analysis and multiple comparisons. The mortality rates were assessed by means of a binomial test with subsequent multiple comparisons. Trends in the nutrition of plantations were evaluated using the linear-regression lines smoothing the macroelement concentrations recorded within a variant in the years of sampling. For each macroelement and variant, the existence of a significant divergence of the time axis and regression line representing a development in macroelement concentration was examined. For each macroelement, a mutual parallelism of regression lines representing the compared variants was also tested. A partial correlation test was used to examine a relationship between developments of height increment and concentrations of foliar macroelements. The methods are described by Anděl (1998). The confidence level of 95% was chosen in all the statistical tests. As it is explained in the text above, the outcomes of soil analyses were not statistically tested. The statistically processed files of the mensurational characteristics consist of the data only that are related to the trees surviving in the autumn of 2004, the data belonging to the dead trees were retrospectively excluded.

RESULTS

Mortality

The mortality of Carpathian birch was relatively low (Table 1). The highest annual mortality rates were registered in the first half of the studied period

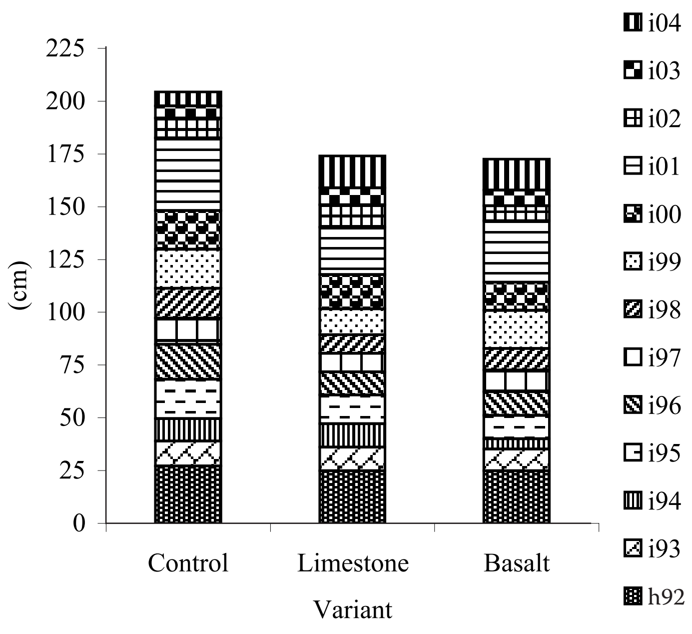

Fig. 1. Average plantation height as registered in the particular treatment variants in 2004

Table 2. Development of annual height increment and periodic annual increment (P.A.I.) in 1993–2004 in the particular treatment variants; x – arithmetic mean, s – standard deviation

Variant		1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	1993–2004
Overall p-value		0.2022	0.0000	0.0000	0.0000	0.0055	0.0000	0.0000	0.0000	0.0000	0.0382	0.0051	0.0038	0.0000
Control	x (cm)	11.7a	10.7b	18.5b	16.6b	12.5b	14.1b	18.5b	18.3b	34.4b	9.5ab	5.8a	6.6a	14.8a
	s (cm)	5.79	10.28	10.42	10.26	8.55	8.83	11.84	12.52	16.01	11.39	7.59	22.92	3.89
Limestone	x (cm)	11.1a	11.1b	13.7a	10.9a	8.8a	8.8a	12.2a	16.3ab	22.4a	10.6b	8.0b	15.2b	12.4b
	s (cm)	6.79	11.45	9.15	9.28	5.20	5.65	9.95	11.89	14.70	10.92	8.05	17.92	3.27
Basalt	x (cm)	10.3a	4.9a	11.0a	11.2a	10.4ab	10.2a	17.9b	13.4a	29.2b	7.0a	7.5b	14.7b	12.3b
	s (cm)	4.81	7.14	10.50	9.20	9.18	8.98	10.59	11.52	16.37	7.76	14.93	20.09	4.00

Figures in individual columns followed by different letters are significantly different

and then decreased. Since 1998 onwards, the annual mortality rates did not exceed 2.1% in any of the compared treatment variants. The lowest total mortality (2004) of 4.1% was recorded in the limestone treatment. The total mortality rates (2004) in the control and basalt treatment were higher and reached 14.8% and 13.4%, respectively. A significant overall heterogeneity in total mortality rates (2004) was detected (p-value = 0.03). The subsequent multiple comparisons, however, did not define any pair of variants, wherein the total mortality rates (2004) significantly differed.

Height growth

The basalt and limestone treatments inhibited the height increment of the birch trees. The superiority of control variant in the height growth of trees is apparent in Fig. 1, which depicts the average plantation height in the particular treatment variants in 2004 (Table 2).

Table 3 summarizes the annual height increments since planting and the periodic annual increment P.A.I. (1993–2004). An overall p-value of the Kruskal-Wallis analysis is included in Table 3 to specify unambiguously the test conclusions of height increment in 1993.

Crown diameter

The crown diameters also indicate negative effects of the limestone and basalt applications on the aboveground biomass production of young Carpathian birches. As Table 3 shows, the trees in the control variant were holding the significant superiority in the crown diameter. In 2004, the crown diameter values of the trees in the limestone and basalt variants were by 20% and 18% lower than those in the control variant.

Stem base diameter

The stem base diameters show the same results as the crown diameter. In the autumn of 2004, the average value of the stem base diameter of the birches in the control variant (100%) was significantly higher than that in the limestone and basalt variant (by 23% and 17%) (see Table 4).

Nutrition status

(move to Tables 5 and 6 in the text below)

In general, the N nutrition seems to have improved regardless of the variant during the assessed period.

Table 3. Development of average crown diameter in the particular treatment variants; x – arithmetic mean, s – standard deviation

Variant		1996	1997	1998	1999	2000	2004
Control	x (cm)	34.0c	44.0c	50.0b	69.0b	90.0b	128.0b
	s (cm)	12.9	17.5	19.0	23.8	26.0	33.3
Limestone	x (cm)	29.0b	33.0b	34.0a	47.0a	63.0a	102.0a
	s (cm)	11.8	12.3	12.6	14.5	19.9	27.2
Basalt	x (cm)	21.0a	25.0a	33.0a	50.0a	78.0a	105.0a
	s (cm)	12.7	14.9	16.6	23.5	72.8	40.1

Figures in individual columns followed by different letters are significantly different

Table 4. Average values of stem base diameter in the particular treatment variants; x – arithmetic mean, s – standard deviation

Variant		1999	2004
Control	x (cm)	3.1b	5.2b
	s (cm)	1.06	1.54
Limestone	x (cm)	2.2a	4.0a
	s (cm)	0.68	1.27
Basalt	x (cm)	2.1a	4.3a
	s (cm)	0.94	1.72

Figures in individual columns followed by different letters are significantly different

In the limestone and basalt variants the increasing trends of N concentration during the assessed time are significant.

The basalt treatment slightly enhanced the foliar P content in the initial years after planting. This difference, however, gradually diminished. A marked rise in foliar P was recorded in 2001, nonetheless, no significant increasing or decreasing linear trend in the foliar P concentrations has been proved for the whole period since planting in any of the variants.

Except for 1995 and 2004, the applied liming seems to have slightly reduced the content of K in the leaves of limed trees compared to the other two variants. In all three variants the K nutrition has significantly improved since planting.

In the limestone treatment, a substantially raised foliar Ca content remained even 11.5 years after liming. No significant increasing or decreasing trend has been proved in this variant. On the other hand, in the basalt and control treatments, the foliar Ca concentrations have significantly increased since planting.

The concentration of Mg in the leaves of limed trees was surprisingly low compared to the further two variants over the years from 1993 to 2001. A change in the variant ranking (in terms of foliar Mg) occurred no sooner than in 2003, though the difference had diminished earlier, by 1996. In the limed variant, however, a significant increasing trend in the foliar Mg concentration has been detected since planting.

The control variant showed the highest proportion of foliar S in five cases of eight sampling years. In all three variants, an increasing trend in foliar S content is apparent and significant.

Nutrition status vs. height growth

When the data of all three variants were pooled, a significant positive correlation was found between

Table 5. N, P and K concentrations (% of dry matter) in birch leaves

Year/variant	N (%)			P (%)			K (%)		
	control	limestone	basalt	control	limestone	basalt	control	limestone	basalt
1993	1.58	1.84	1.44	0.14	0.14	0.15	0.48	0.43	0.46
1994	1.83	1.50	1.54	0.13	0.14	0.16	0.31	0.27	0.33
1995	1.76	1.66	1.71	0.16	0.15	0.20	0.35	0.38	0.37
1996	2.03	1.62	1.62	0.20	0.18	0.19	0.43	0.38	0.45
1999	2.53	2.15	2.33	0.20	0.17	0.20	0.47	0.40	0.45
2000	2.10	2.05	2.22	0.15	0.14	0.15	0.56	0.55	0.55
2001	1.59	2.50	2.39	0.26	0.29	0.25	0.46	0.41	0.48
2003	2.01	2.02	2.00	0.15	0.15	0.14	0.53	0.49	0.50
2004	2.50	2.56	2.56	0.16	0.17	0.16	0.58	0.59	0.61

Table 6. Ca, Mg and S concentrations (% of dry matter) in birch leaves

Year/variant	Ca (%)			Mg (%)			S (%)		
	control	limestone	basalt	control	limestone	basalt	control	limestone	basalt
1993	0.50	0.76	0.35	0.284	0.218	0.342	–	–	–
1994	0.47	0.47	0.36	0.357	0.239	0.345	0.139	0.126	0.108
1995	0.39	0.58	0.37	0.387	0.215	0.380	0.176	0.159	0.156
1996	0.46	0.60	0.48	0.245	0.210	0.250	0.144	0.122	0.110
1999	0.52	0.66	0.53	0.144	0.141	0.146	0.170	0.182	0.196
2000	0.39	0.51	0.43	0.210	0.204	0.203	0.280	0.169	0.209
2001	0.63	0.62	0.67	0.382	0.322	0.356	0.251	0.236	0.224
2003	0.69	0.80	0.72	0.559	0.570	0.543	0.206	0.206	0.209
2004	0.66	0.81	0.72	0.470	0.490	0.470	0.238	0.256	0.261

developments of height increments of trees and content of foliar P (correlation coefficient $r = 0.73$) and S ($r = 0.58$). A significant negative correlation between height increment and content of foliar Mg was found ($r = –0.49$). When the data of each variant were evaluated separately, no significant correlation between the nutrition status and height growth was found.

Soil chemistry inside the planting holes

The liming markedly increased the reaction of the 0–10 cm layer. In the 10–20 cm layer (Table 7), the increase in soil reaction as a result of liming was also observable but not as striking as in the 0–10 cm zone. A minor positive effect of basalt grit on soil reaction was detected.

In the 0–10 cm layer, the liming induced a slight decrease in soil organic matter (SOM). The highest content of SOM was registered in the variant treated with basalt grit. In the 10–20 cm layer, the SOM content was slightly higher in the variants treated with basic amendments compared to the control.

The average content of soil N in the 0–10 cm layer of limed variant was lower than in the control. However, the lowest content in soil N was registered in the basalt variant. In the 10–20 cm layer, the soil N contents of all three experimental treatments were similar.

In the 0–10 cm layer, the sum of exchangeable bases (SEB) and base saturation (BS) in the limed variant were strikingly higher compared with the control. In the 10–20 cm layer, the difference between the limed and control variants was even greater, though, the SEB and BS values were lower than in the 0–10 cm zone. The application of basalt grit also markedly (however not as strikingly as limestone) increased the SEB and SB values.

Table 7. Soil properties in September 2002

Treatment		The 0–10 cm horizon			The 10–20 cm horizon		
		control	limestone	basalt	control	limestone	basal
pH/H_2O	(–)	4.2	6.2	4.5	4.2	4.9	4.4
pH/KCl	(–)	3.2	5.6	3.1	3.4	3.7	3.0
Soil organic matter (SOM)	(%)	12.3	11.1	18.0	4.8	5.5	5.4
N_{tot}	(%)	0.38	0.31	0.17	0.15	0.16	0.17
Sum of exchangeable bases (SEB)	(meq/100 g)	4.0	48.0	12.9	0.2	11.4	2.2
Base saturation (BS)	(%)	27.3	95.7	44.6	2.2	58.0	18.7
Cation exchange capacity (CEC)	(meq/100 g)	14.5	50.1	28.9	10.1	19.6	11.5
P_2O_5	(mg/kg)	93	57	189	107	99	157
K_2O	(mg/kg)	118	57	275	48	40	42
CaO	(mg/kg)	960	37,333	2,093	280	2,933	467
MgO	(mg/kg)	248	740	732	93	107	143
Al^{3+}	(meq/kg)	32.7	3.4	54.1	47.7	17.6	44.2

In the 0–10 cm layer, the application basic amendments induced a substantial rise in the cation exchange capacity (CEC). The CEC values of the limestone and basalt variants were almost 3.5 fold and 2 fold higher than in the control variant. In the 10–20 cm layer, the CEC values in the control and basalt variants were similar, while the CEC level registered in the limed treatment was twice as high.

In both the layers (0–10 and 10–20 cm), liming reduced the quantity of exchangeable P while the application of basalt increased it substantially.

The liming reduced the content of exchangeable K in the 0–10 cm layer, while the application of basalt increased it markedly. In the 10–20 cm layer, the contents of K were slightly reduced in the variants treated with basic amendments compared to the control.

The liming massively increased the exchangeable Ca content in the 0–10 cm horizon. The basalt grit also raised the Ca content, nevertheless, to a substantially less extent. In the 10–20 cm layer, the results were analogous, though, the Ca contents were lower.

The application of both the basic amendments augmented the proportion of exchangeable Mg in the 0–10 cm zone. Slight increases in the Mg content as a result of the liming or basalt grit application were also revealed in the 10–20 cm compartments.

The liming reduced the content of exchangeable Al in the 0–10 cm and the 10–20 layer of the planting holes whereas Al was raised by the applied basalt grit.

DISCUSSION

Birch plantations

It is highly desirable to determine the mechanism through which basic amendments negatively affect the growth performance of Carpathian birch. This species seems to be a taxon which presumably demands acidic soils not only because of the less fierce competition of other species on poor acidic sites but also because it is so much physiologically adapted to soil acidity that it finds its ecological optimum on acid sites. Therefore, a marked increase in soil pH may retard the growth of Carpathian birch, although other tree species may respond positively to this treatment. On the other hand, the basic amendments did not result in any fatal decline of Carpathian birch plantation despite high dosages applied and profound changes in soil chemistry induced by the treatments.

Other processes in the soil environment might also play a role such as nitrogen content or altered physical properties of soil in the variants treated with basic amendments (Balcar 2001). Reasons for these further hypotheses are based on the fact, that basalt grit did not raise the soil pH, however led to analogous plantation response as liming.

The increasing concentrations of foliar S and N might indicate a persisting air-pollution load on the site, which is in agreement with the outcomes of a long-term monitoring presented by Slodičák et al. (2005).

The positive correlation between foliar S and height growth may be explained as follows: a more intensive growth is in relation with the formation of a greater amount of foliage and new roots. Thus sulphur uptake by roots from soil and its scavenging from air (a larger leaf surface) can be increased. The positive correlation between foliar P and height growth does not need any comments. An explanation of the negative correlation between foliar Mg and growth of birches needs a further study.

SOIL CHEMISTRY

A poor neutralizing effect of the applied basalt grit was caused mainly by its too coarse granularity, though a lower solubility and different chemical composition of silicate basalt played a role as well. Dolomitic limestone has a high neutralizing potential (van Hees et al. 2003a), however, an appropriate grain-size composition is necessary to achieve a desirable ameliorative effect (Meiwes et al. 2002).

The most serious risks inherent in the use of basic amendments in the forests are related to SOM and soil N dynamics. The liming usually promotes the soil microbial activity, and thus it might increase excessively microbial respiration and mineralization of the SOM (Marschner, Wilczynski 1991; Kreutzer 1995; Anderson 1998; Lorenz et al. 2001; van Hees et al. 2003b). This treatment frequently enhances N mineralization and nitrification (Nohrstedt 2002; van Hees et al. 2003a; Geibe et al. 2003), which could lead to the leaching of NO_3. Losses of SOM and N as a consequence of applied liming were described for example by Marschner and Wilczynski (1991), Kreutzer (1995), Podrázský (1995), Nilsson et al. (2001). On the other hand, in the soils with a high C to N ratio (approximately 30 and more), liming may result in the immobilization of N by microbial biomass (Neale et al. 1997).

In the limed variant, the results indicate a very slight shift in the mass of SOM from the 0–10 cm horizon to the 10–20 cm layer. This shift might be a result of accelerated mineralization of SOM in the upper parts of the planting holes.

Analogously, a lower percentage of soil N in the 0–10 cm layer of both the variants treated with basic agents and the increased N content in the 10–20 cm layer of these ameliorated variants may indicate an enhanced N leaching.

The amendments from silicate basic rocks induce similar processes as liming in terms of SOM and soil N, however, when applied in higher dosages compared to liming.

The unusually low SOM percentage in the 0–10 cm horizon within the planting holes is presumably a result of the mixing of humus horizons with mineral soil and eventual addition of mineral amendments.

As expected, the liming raised the SEB and BS, which is in accordance with the findings of many authors (Podrázský, Balcar 1996; Bakker et al. 1999a,b; Lundström et al. 2003; van Hees et al. 2003a, etc.). The SEB and BS in planting holes were also elevated by the application of basalt grit. This elevation was not as pronounced as in the case of liming but it might have been more valuable in qualitative terms, because also the K cations, in contrast to liming, surely participated in it.

The increased CEC as a result of liming and also basalt grit application is in line with the expectations and findings of other authors (Podrázský 1995; Bakker et al. 1999a; Braekke 1999a; Lundström et al. 2003; Kuneš 2003). This increase in CEC might be ascribed to the pH-depended character of this soil characteristic (Bakker et al. 1999b).

The fixation pattern of P in soil is very complex. The phosphate forms salts with Fe, Al, Ca or Mg depending on the soil reaction (Braekke 1999b). At the low end of the pH spectrum, the least soluble aluminum salts are dominant (Binkley 1986). On one hand, the liming could increase an exchangeable P content by raising the soil reaction (pH) and promoting mineralization of SOM, on the other hand this treatment adds Ca cations into soil and thus increases the probability of the formation of insoluble Ca-phosphates. The increased soil pH could also promote phosphorus immobilization by microorganisms (Fransson et al. 1999). On the whole, it is difficult to predict what mechanism and what P dynamics finally prevail. In our experiment, the applied liming decreased the content exchangeable P. By contrast, the basalt grit increased the exchangeable P content in soil due to the fact that this rock contains P within its chemical composition and also contains less Ca and Mg compared to limestone.

In the limed variant, a markedly lower content of exchangeable K was registered. Similar negative effects of liming on exchangeable K content were described e.g. by Podrázský and Balcar (1996) and Geibe et al. (2003). On the other hand, the applied basalt grit increased the concentration of exchangeable K; probably as a consequence of silicate weathering.

In the 0–10 cm horizon of the limestone variant, the increased content of exchangeable Ca and Mg is in accordance with expectations and with findings of authors such as Jönsson (2000), Frank and Stuanes (2003), van Hees et al. (2003a), Meiwes et al. (2003), etc. The limestone induced also a marked rise in Ca concentration in the 10–20 cm layer. A similar rise, however, was not observed for Mg. The content of Mg was only slightly elevated in the 10–20 cm zone compared to the control. The authors speculate that this might have been a result of leaching. Compared to Ca, Mg is characterized by higher mobility (Brahmer 1994; van Hees et al. 2003a; Lundström et al. 2003; Geibe et al. 2003). Because the CEC of soil in the 10–20 cm layer is considerably lower than in the 0–10 cm horizon, a lot of Mg may have been leached away over the time span of nine and a half years.

The ability of liming to reduce the exchangeable Al has already been well documented (Bakker et al. 1999a,b; Jandl et al. 2001; Wargo et al. 2002, etc.). With the acidification of soils, the issue of this element is becoming highly topical in air-polluted areas. Plants might be adversely affected by ionic Al either through antagonistic interference with cation uptake or through damage to plant cells from aluminium interactions with biomolecules (Cronan, Grigal 1995).

However, the Al toxicity is rather a problem of mineral soils. In organic soils or in organic layers, the Al is likely to be complexed in insoluble forms by the organic matter (Brady, Weil 2002). Forest top soils are relatively rich in organic components. Moreover, some field experiments carried out in real forest conditions cast doubt on the key role of Al toxicity expressed as the Ca/Al ratio (Hahn, Marchner 1998a,b). Nygaard and Wit (2004) suggest that forest ecosystems seem to be more robust compared to what laboratory experiments and experiments on cultivated soils have shown.

CONCLUSIONS

The Carpathian birch is a suitable species for the replanting of extreme acidic mountain sites. Provided that the game is excluded (game-proof fenced areas), Carpathian birch shows a low mortality rate and grows well in the clear-felled patches. The birch soon forms a cover which is necessary for the reintroducing of more sensitive tree species, and might also stimulate the cycling of organic matter and nutrients in the ecosystem because it annually produces a litter which is of high ameliorative potential (Podrázský et al. 2005).

The Carpathian birch seems to be a taxon which presumably demands acidic soils. A sharper increase in soil pH may thus negatively affect its growth. However, there are also other factors such as nitrogen availability or physical properties of soil that might play a role. An exact definition of the mechanism (or mechanisms) through which the applied basic amendments induced a growth retardation of Carpathian birch is still to be done and should be a topic of further research.

Despite some growth retardation of Carpathian birch, the application of basic amendments did not result in any fatal decline of the treated experimental plantations. This decline did not occur in spite of the fact that high dosages had been applied directly to the roots of the trees and although marked changes in soil chemistry occurred in the soil environment of the chemically treated plants.

The liming raised soil reaction, soil base content, base saturation, cation exchange capacity and reduced the exchangeable Al content. On the other hand, this measure slightly decreased the amount of soil organic matter, negatively affected soil N, exchangeable P and K.

The too coarse basalt grit did not raise a soil reaction as markedly as the limestone powder and its influence on the sum of exchangeable bases, base saturation and cation exchange capacity was also much less pronounced compared to liming. By contrast to the limestone applied, the basalt grit markedly raised exchangeable K and P contents. On the other hand, it elevated exchangeable Al and substantially reduced the content of soil N. The finely ground powders are only suitable for precise application in order to achieve desirable effects on soil chemistry.

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Vliv jamkové aplikace moučky dolomitického vápence a čedičové drti na odrůstání výsadeb břízy karpatské (*Betula carpatica* W. et K.) a na půdní chemismus v imisemi postižených Jizerských horách

ABSTRAKT: Cíl studie spočívá v posouzení růstového potenciálu břízy karpatské *(Betula carpatica* W. et K.) a její růstové odezvy na změnu půdního chemismu po aplikaci čedičové drti a mletého dolomitického vápence. Bříza karpatská prokázala, že je vhodným druhem pro zalesňování extrémních kyselých horských stanovišť. Vykazuje relativně nízkou mortalitu, dobře odrůstá a brzy vytváří zápoj nezbytný pro vnášení dalších citlivějších cílových druhů. Aplikace dolomitického vápence i čedičové drti zpomalila růst břízy karpatské. Vápnění zvýšilo půdní reakci, obsah půdních bází, nasycení sorpčního komplexu bázemi, kationtovou sorpční výměnnou kapacitu a redukovalo koncentraci pohyblivého hliníku. Na druhou stranu vápnění mírně snížilo množství oxidovatelné organické hmoty a negativně ovlivnilo půdní N, výměnný P a K. Čedičová drť obsah výměnného P a K zvýšila, vyvolala ale jen nepatrný nárůst půdní reakce. Rovněž její vliv na obsah výměnných bází, nasycení sorpčního komplexu bázemi a na kationtovou sorpční výměnnou kapacitu byl ve srovnání s vápencem podstatně menší. Čedičová drť zvýšila podíl pohyblivého hliníku a redukovala obsah půdního N.

Klíčová slova: bříza karpatská (*Betula carpatica* W. et K.); Jizerské hory; chemická meliorace; vápnění; čedičová drť; lesní půdy; kyselá depozice; lesní ekosystémy

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