Influence of limestone and amphibolite application on growth of Norway spruce plantation under harsh mountain conditions

T. Koňasová[1,4], I. Kuneš[1], M. Baláš[1], K. Millerová[1], V. Balcar[2], O. Špulák[2], M. Drury[3]

[1]*Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Prague, Czech Republic*

[2]*Forestry and Game Management Research Institute, Strnady, Opočno Research Station, Opočno, Czech Republic*

[3]*National School of Forestry, University of Cumbria, United Kingdom*

ABSTRACT: The results of a fifteen-year period of investigations conducted on Norway spruce in the upper plateau of the Jizerské hory Mts. were summarised. The objectives were to evaluate the growth performance of an experimental plantation under harsh environmental conditions and assess the effects of amendments as well as the influence of the forest site variability on growth performance and survival of young spruces. The following treatments were distinguished: (1) lower control, (2) limestone and (3) amphibolite treatments on a less exposed slope of the ridge and (4) upper control on a summit of the mountain ridge. Principle characteristics such as mortality rate, height, annual height increment, stem base diameter, crown diameter and nutritional status were summarized and evaluated. Significant differences between treatments were recorded in heights. The trees fertilized with amphibolite were significantly taller than the control ones in thirteen out of the fifteen evaluated years and the applied limestone improved heights in ten years out of the fifteen evaluated years. A positive effect of amphibolite treatment on stem base diameter was proved in three of the four assessed years and was persisting till 2007 (last measurement of this characteristic), the positive effect of limestone was lasting up to 2006. The considerable role of the site variability was apparent from a comparison between the upper and lower control although they were in a very close position to each other, growth increment of the spruces on the ridge was significantly lower. Temporarily lower N concentration was recorded in the fertilized treatments in comparison with their respective control. The concentration of P was low and decreased to the limit of deficiency in all treatments, P seems to be the most limiting macroelement in the area.

Keywords: *Picea abies*; forest soil; chemical amelioration; growth; nutrition

The northern border mountains in the Czech Republic belong to the Black Triangle region (Majer et al. 2005) that was seriously affected by air pollution (Kandler, Innes 1995; Hrkal 2004; Balcar 2005). The massively increased concentrations of SO_2 and NO_x in the air originated mostly from the brown coal burning thermal power plants and heavy industry situated in the region (Hůnová, Ostatnická 2001; Křeček, Hořická 2006). The extensive area of forests declined as a result of the air and soil pollution combined with climatic stresses and insect pest attacks (Křeček, Hořická

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2002; Vacek 2003). The Jizerské hory Mts. were a symptomatic example of the environmental disaster occurring in the whole region during the 1970s and 1980s. The total area of clear-felled tracts in the most exposed summit plateau of the Jizerské hory Mts. amounted to 12,000 ha (Balcar et al. 1994, Lomský et al. 2011). Even after a considerable decrease in the production of pollutants in the Black Triangle region during the 1990s (Fottová, Skořepová 1998), the reforestation of the high-situated areas of the Jizerské hory Mts. was difficult due to polluted soil and harsh microclimate reigning in clear-felled tracts in the extreme mountain environment.

In the 1990s, initiated by difficulties in reforestation, several field experiments searching for the ways to support young trees planted under harsh conditions were installed (Balcar 2001). One of the tested supportive approaches is the initial fertilization of young tree plantations to promote their growth and survival. Young trees planted under the harsh mountain conditions suffer from a post-planting shock which causes considerable growth retardation and often contributes to significant plant losses (Kriegel, Bartoš 2004; Kuneš et al. 2004b; Grossnickle 2005). Precisely applied amendments are expected to increase the survival rate and support the height growth (Óskarsson et al. 2006) of trees so that the terminal leaders of trees sooner escape from the ground-frost and weed-competition zone. The experiment compares the effects of amphibolite and limestone on the growth of Norway spruce. Limestone in comparison with amphibolite is expected to increase the pH of soil more markedly and the response is expectable in a shorter time. On the other hand, slow-soluble amphibolite exerts a less profound effect on the pH, nonetheless, next to Mg and Ca, the amphibolite powder provides also other nutrients (Materna 1963; Nárovec et al. 1995; Vavříček 1997); see the text below. Moreover, the effects of amphibolite are expected to last longer (slower solubility). Since both basic materials were easily available to forest practitioners in the region, the experiment was designed to find out which one is more suitable to promote growth performance and reduce mortality in a short- to medium-term time horizon.

The purpose of the investigation was (a) to assess the growth of Norway spruce under harsh mountain conditions, (b) to evaluate the growth response of Norway spruce to the chemical amelioration and (c) to investigate the influence of the forest site variability on the growth performance and survival of spruce plantation.

MATERIAL AND METHODS

The experimental plantation of Norway spruce (*Picea abies* [L.] Karst.) is situated in the Jizerské hory Mts. (50°49'34''N, 15°21'19''E, Northern Bohemia), on the (i) south-facing slope and (ii) summit of the Central Jizera Ridge (Střední Jizerský hřeben) at an altitude of 960–980 m a.s.l. The climatic conditions of the area can be characterized by the mean annual air temperature of 5.1°C (1996–2007) and the mean annual precipitation of 1,093 mm (1994–2007) (Balcar, Kacálek 2008). The bedrock was determined as biotitic granite. In the lower part of the site (on the slope) the well-drained soil was determined as a mountain humus podzol or Ferro-humic Podzol (Phf) (according to the ÚHUL or FAO classification, respectively). Stratification (2003): L integrated in a greensward (0–2 cm), F (2–5.5 cm), H (5.5–10 cm), Ah (10–13 cm), Ep (13–19 cm), B (19+ cm). The soil on the summit was determined as peat podzol or Histo-humic Podzol (Pho) (ÚHUL or FAO classification, respectively) with a tendency to temporal water-logging as a result of the flat-shaped summit of the ridge. Stratification (2003): L integrated in greensward (0–2 cm), F (2–8 cm), H (8–12 cm), A_H (12–13 cm), Ep (13–17 cm). As for soil chemistry, the principle characteristics in the slope and summit part of the site are summarised in Table 1.

Different soil types with different chemistry and hydric regimes together with some differences in climatic characteristics between slope and summit (Balcar et al. 2012) could be considered the main sources of the site variability that was reflected in the experimental design (see the text below).

The experimental Norway spruce plantation was established in 1994 in a game-proof exclosure. It consists of four treatments: (1) the nonfertilized lower control (LC) is situated on the less exposed slope of the ridge and serves as a control for the fertilized (2) limestone (LT) and (3) amphibolite (AT) treatments situated at the same part of the experimental site. The nonfertilized (4) upper control (UC) was installed on a climatically more exposed summit of the ridge and serves for evaluating the importance of forest site variability and site relief influence. The positional and altitudinal distance of the UC from the other three treatments is ca 150 m and 20 m, respectively.

Altogether 500 transplants aged four (2 + 2) years, originating from the Krkonoše Mts. (Northern Bohemia), from the 8^{th} forest altitudinal (vegetation) zone (according to the Czech typological system; see e.g. Viewegh et al. 2003) were divided into

10 subplots (10 × 10 m). Each subplot contained 50 individuals at a spacing of 1 × 2 m. The LC and UC each included three subplots (150 trees) and each of the fertilized treatments consisted of two subplots (100 trees).

The trees in the AT and LT were fertilized when planted in 1994. The amendment was incorporated into the soil in a planting hole of each tree. In the AT two kilograms of amphibolite powder per tree were used. The pulverized amphibolite contained 0.13% P, 0.82% K, 7.9% Ca and 4.82% Mg. The particle size distribution of the amphibolite powder was as follows: 5% of particles with a diameter over 0.25 mm, 53% of particles 0.25–0.05 mm in size and 42% particles below 0.05 mm in size.

Dolomitic limestone was used in the dosage of 1 kg per tree and contained 21.5% Ca and 11.25% Mg. The particle size distribution was as follows: 5.8% of particles with a diameter over 1 mm, 16.3% of particles 0.5–1 mm, 20.4% of particles 0.2–0.5 mm and 57.2% of particles below 0.2 mm.

Tree heights and crown diameters were measured with a scaled rod (for heights and crowns to the nearest 1 cm and 10 cm, respectively). The stem base diameter was measured with a calliper (to the nearest 1 mm). Mortality and height growth as principal characteristics were evaluated annually, the other (additional) plantation parameters usually at longer intervals depending on time and financial possibilities of the research team.

Differences in mortality could affect the biometric parameters. The mean values of biometric parameters in treatments with higher mortality rates are commonly less influenced by the weakest trees since these die sooner and are excluded from the data file. The dynamics of the growth performance was therefore evaluated (*i*) on the basis of the results of the measurements of all trees living in 2008 (referred to as whole treatments in the text below), and (*ii*) on the basis of 20% of the highest trees. The percentage is related to the numbers of trees planted in 1994, i.e. the 10 highest trees per subplot, in total 30 individuals per treatment in the LC and UC and 20 individuals in the AT and LT. The selection of the tress included in the group of 20% of the highest individuals was executed on the basis of sorted height values from 2008 (reference year).

Nutritional status of the experimental plantations was assessed for whole treatments by chemical analyses of current-year needles. Analyses of the nutritional status were not intended at the beginning of the experiment. Therefore, they were not conducted consistently.

Sampling was realised in 1996, 2001 and 2002 in the off-season period. In our study the fertilized treatments – AT and LT – and their respective control – LC were only evaluated (the UC was not included). One to three samples were taken per each treatment. The samples consisted of needles from at least 10 randomly chosen trees. The sampled material originated from sunned parts of crowns (the second to third whorl). Total content of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S) was determined. The evaluation criteria for the nutrient concentrations used by different authors can differ to some extent, e.g. the limit of deficiency for N reported by De Vries et al. (1998) or Renou-Wilson, Farell (2007) is 1.20%, according to Šrámek et al. (2004) the N deficiency limit is 1.30%. Similarly, the values for Ca deficiency used by De Vries and Šrámek (0.15%) are considerably higher than those published by Renou-Wilson and Farell (0.05%). Therefore we finally decided to use the limits of nutrient deficiency which were already used in the Jizerské hory Mts. by Kuneš (2003). These limits are based on the study conducted by De Vries et al. (1998), nonetheless, as for S concentration, the limits were modified according to the experiences acquired in the Jizerské hory Mts. and other S polluted mountains in the Czech Republic.

The foliar nutrient ratios were classified according to limits by De Vries (1998). The analyses were

Table 1. Chosen principal chemical properties of untreated soil in the slope and on the summit of the experimental site in autumn 2002

Position on the site	Soil layer (cm)	pH/KCl	$N_{Kjeldahl}$ (%)	P_2O_5	K_2O	CaO	MgO
				(mg·kg^{-1})			
Slope	0–10	3.69	0.85	127.3	127	1907	568
	10–20	3.77	0.22	89.0	49	573	170
Summit	0–10	3.13	0.52	82.0	141	973	264
	10–20	3.43	0.14	95.7	24	220	68

Available phosphorus and soil bases were extracted in citric acid solution conducted in the Tomáš Laboratory in Opočno. Analytic methods to determine the chemical composition of assimilatory apparatus were described by Zbíral (1994). In English the analytic methods were shortly summarized by Kuneš et al. (2012).

The values of height, height increment, stem base diameter and crown diameter were statistically analysed using the non-parametric Kruskal-Wallis Analysis with post-hoc Nemeny's multiple comparisons. STATISTICA 8.0 (StatSoft, Inc.) software was used for the statistical analysis. The chosen confidence level was 95%. The statistically processed files of the mensurational characteristics consisted of the data only relating to the trees alive in the autumn of 2008. Data belonging to the dead trees were retrospectively excluded. For a comparison of the treatment subgroups containing 20% of the highest trees the same statistical procedures were used as for a comparison of whole treatments.

Mortality was analysed by chi-square test for independent samples with subsequent multiple comparisons for binomial distributions using S-Plus 6.1 (Insightful Corp.) software. The procedure is described e.g. by Anděl (1998) and is based on the paper by Hayter (1984).

RESULTS

Height growth

Concerning the comparison of the whole treatments (Fig. 1), the ameliorated trees were significantly higher since 1996 than the trees from both the UC and LC. In the last four years the heights of the LC differed significantly from the AT and UC. There were no significant differences between the AT and LT during the reference period (1994 to 2008). In 2008 the mean heights of the treatments were as follows: 390 cm (AT), 360 cm (LT), 322 cm (LC) and 215 cm (UC). The AT was significantly higher than its respective LC and non-significantly higher than the LT. No significant difference between the LT and LC was found in 2008.

When the growth was evaluated on the basis of 20% of the highest trees, the differences between the LC and UC increased. The values of the mean height of 20% of the highest trees in 2008 were as follows: 517 cm (AT), 478 cm (LT), 413 cm (LC) and 297 cm (UC).

Increments

As for the first growth season (1994), there were no significant differences in annual height increments among whole treatments (Table 2). In the following years, however, the UC mostly showed significantly lower increments in comparison with the LC (with the exception of 1999 and 2006) as well as in comparison with the LT and AT (with the exception of 2006). When comparing the ameliorated treatments and their respective control (LC), the differences can be found in two years (1996, 1998) concerning the LT and in six years (1995, 1996, 1997, 2004, 2005, 2007) in the case of AT. No significant differences between the LT and AT were recorded.

As for the height increment of 20% of the highest of trees, the development was analogous as the development of whole treatments. The values of the mean periodic annual increment (94-08) of 20% of the highest trees per treatment were as follows:

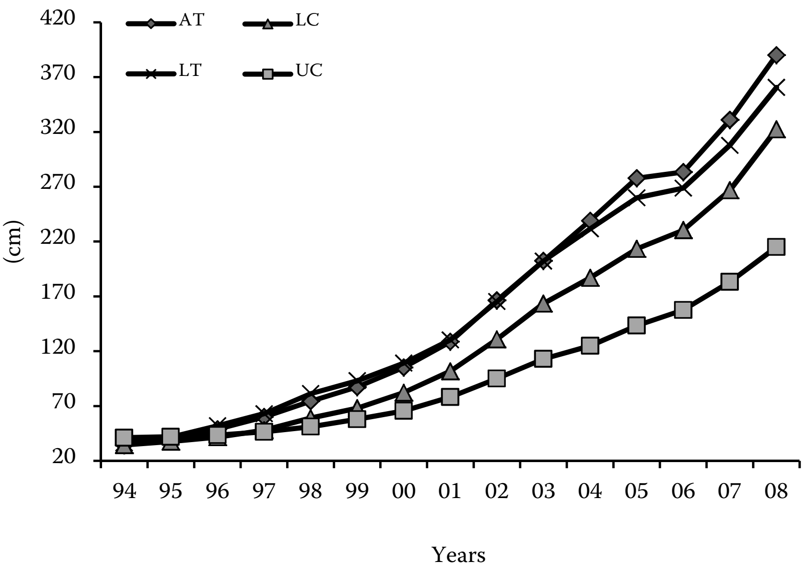

Fig. 1. Development of average plantation height of whole treatments
AT – amphibolite treatment, LT – limestone treatment, LC – lower control, UC – upper control

Table 2. Development of annual height increment values and periodic annual height increment (1994–2008) of whole treatments (in cm)

Year/Treatment		1994	1995	1996	1997	1998	1999	2000	2001
AT	x	6.0[a]	6.3[c]	8.1[c]	11.2[c]	14.3[bc]	12.9[b]	17.9[b]	23.4[b]
	s	3.32	7.55	6.47	10.55	10.20	7.63	10.75	11.21
LT	x	6.0[a]	5.4[bc]	10.3[c]	11.1[bc]	18.4[c]	11.7[b]	16.1[b]	21.2[b]
	s	3.22	5.12	6.35	8.05	10.02	7.46	9.66	11.23
LC	x	5.0[a]	3.2[b]	4.0[b]	6.3[b]	11.0[b]	9.1[ab]	14.1[b]	19.5[b]
	s	3.05	4.25	3.68	6.60	9.7	7.46	10.06	11.65
UC	x	5.5[a]	0.9[a]	1.5[a]	2.9[a]	4.7[a]	6.8[a]	7.7[a]	12.6[a]
	s	2.50	1.60	1.49	2.70	4.05	5.46	6.84	8.56
		2002	2003	2004	2005	2006	2007	2008	1994-2008
AT	x	37.8[b]	36.0[b]	36.6[c]	38.8[c]	5.5[a]	47.6[c]	59.2[b]	24.1[c]
	s	17.14	19.06	20.64	16.93	53.47	25.58	21.26	12.14
LT	x	35.0[b]	36.9[b]	29.3[bc]	28.4[bc]	8.9[a]	39.0[bc]	52.7[b]	22.0[bc]
	s	16.54	20.39	18.01	20.57	23.69	21.68	23.18	7.15
LC	x	29.1[b]	32.5[b]	23.5[b]	26.4[b]	17.1[a]	36.4[b]	55.7[b]	19.5[b]
	s	14.47	17.55	17.00	15.08	22.47	19.71	21.39	6.52
UC	x	16.8[a]	17.9[a]	11.9[a]	18.5[a]	14.4[a]	25.6[a]	31.7[a]	12.0[a]
	s	15.76	14.78	14.31	12.56	17.02	18.19	19.02	6.53

Figures in the columns followed by different letters are significantly different; AT – amphibolite treatment, LT – limestone treatment, LC – lower control, UC – upper control

32 cm (AT), 29 cm (LT), 26 cm (LC) and 18 cm (UC).

Stem base diameter

As for whole treatments, the effect of amphibolite application on the mean stem base diameter in the AT as compared to its respective mean stem base diameter in the LC (Table 3) was significant in 2004, 2006 and 2007. The limestone application influenced positively the stem base diameter in two growth periods out of the four assessed. No significant differences were proved between the AT and LT (Table 3).

The development of 20% of the highest trees brought similar results. For example in 2007 the stem base diameters were as follows: 9.8 cm (AT), 9.2 cm (LT), 8.2 cm (LC) and 6.8 cm (UC). As for the statistical analysis, the comparison yielded the same re-

Table 3. Mean stem base diameter (cm) of whole treatments

Year/Treatment		1998	2004	2006	2007
AT	x	1.6[b]	5.7[c]	7.1[b]	8.2[c]
	s	0.95	1.40	1.74	2.04
LT	x	1.7[b]	5.4[c]	7.5[b]	7.5[bc]
	s	0.40	0.35	0.51	0.50
LC	x	1.4[ab]	4.4[b]	5.6[a]	6.6[b]
	s	0.45	1.95	4.84	2.75
UC	x	1.3[a]	3.4[a]	4.4[a]	5.0[a]
	s	0.52	1.86	2.24	2.61

Figures in the columns followed by different letters are significantly different: AT – amphibolite treatment, LT – limestone treatment, LC – lower control, UC – upper control

Table 4. Development of crown diameter values (cm) of whole treatments

Year/Treatment		2004	2006	2007
AT	*x*	155.2[b]	180.2[b]	197.5[b]
	s	38.15	45.46	53.25
LT	*x*	148.1[b]	162.2[b]	179.8[b]
	s	15.10	15.04	17.08
LC	*x*	135.2[b]	152.4[ab]	168.7[b]
	s	43.72	49.75	54.79
UC	*x*	101.5[a]	124.2[a]	136.3[a]
	s	46.50	51.61	55.30

Figures in the columns followed by different letters are significantly different; AT – amphibolite treatment, LT – limestone treatment, LC – lower control, UC – upper control

sults as the comparison of stem base diameters of all individuals.

For evaluating the impact of amelioration on stability of trees the height/stem base diameter ratio of whole treatments (slenderness ratio for further reference) was used. Four years after planting (1998) a higher slenderness ratio was recorded in the LT. However, in 2007 the slenderness ratios equalised in all three treatments and were as follows: 40.6 (AT), 41.0 (LT) and 40.7 (LC).

Crown diameter

The mean crown diameter of whole treatments (Table 4) indicates that there was no observable positive effect of the amelioration on the width of spruce crowns in the later years of the reference period. A difference was proved only between the UC and the ameliorated treatments (all evaluated years) and between UC and LC (2004 and 2007).

However, when 20% of the highest individuals were compared, significant differences between the AT and its respective LC were proved in all three evaluated years. In 2007 the crown diameters of 20% of the highest trees were as follows: 229 cm (AT), 222 cm (LT), 198 cm (UC) and 179 cm (UC).

Mortality

Initially the lowest mortality rate was recorded in the LT and the highest one in the AT (Fig. 2). In 2007, nonetheless, the LT mortality rate increased up to 46% and rose above the mortality rate recorded in the AT. The mortality increase in the AT after sharp upswing in 1997 ceased already in 1998 (43%).

Significant differences between the LT and its respective LC were recorded in the first thirteen years (1994–2006). Differences between the AT and LC were recorded in the first two years (1994–1995) and in the last two years of investigation (2007–2008).

The total mortality rate in 2008 significantly differed between the AT (43%) and UC (61%) and between the AT and LC (62%).

Nutrition of plantation

As for the evaluation of the nutritional status, data on the chemical analysis of foliage from 1996, 2001 and 2002 were available (Tables 5 and 6).

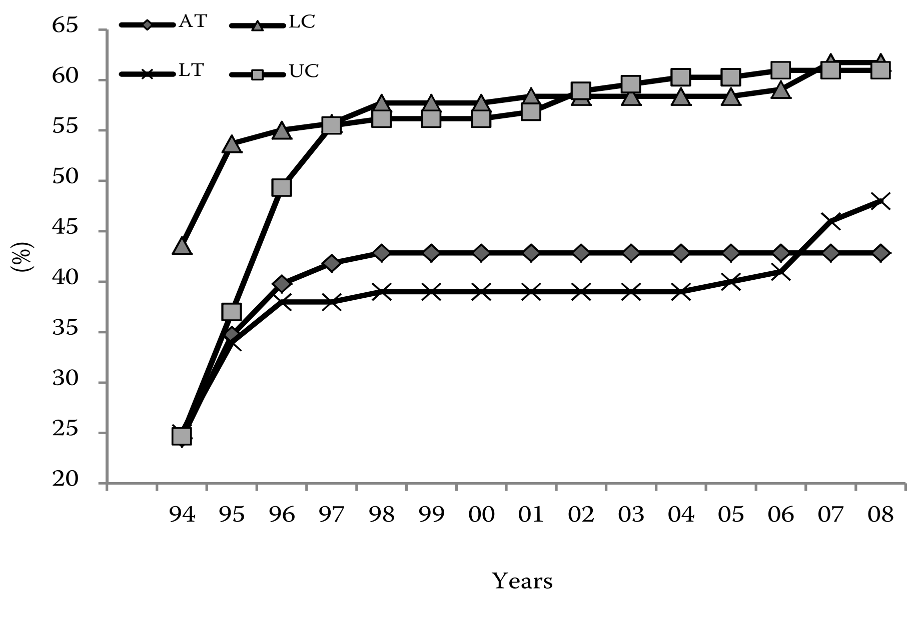

Fig. 2. Overall mortality development of particular treatments
AT – amphibolite treatment, LT – limestone treatment, LC – lower control, UC – upper control

Nitrogen. The mean values of N concentration ranged between 1.28% (LT in 1996) and 1.97% (LC in 1996). In 1996 the LC showed a markedly higher N concentration than the fertilized treatments. Later, in 2001 and 2002, such a marked difference was not observed. Despite some fluctuations in time and differences among treatments, the amounts of nitrogen were above the limit of deficiency in all three evaluated years.

Phosphorus. The mean values of P concentration ranged between 0.11% (LT in 2002) and 0.21% (AT in 1996). Results showed a decreasing tendency of phosphorus concentrations in the course of the reference period. In 2002 the P concentrations in all three treatments were only slightly above the deficiency limit.

Potassium. From 1996 to 2001 the K concentrations increased in all three treatments. However, a decrease in K concentrations was observed between 2001 and 2002. The lowest concentration of K was recorded in the LT (0.44%) in 2002, the highest one in the LC (0.68%) in 2001.

Calcium. The application of amphibolite seems to keep increased concentrations of Ca during the whole observed period. On the other hand, the effect of limestone was rather ambiguous: in 2002, the limed treatment (LT) showed the lowest Ca concentration in needles from all three compared treatments. Calcium concentrations in 2002 were as follows: 0.46% (AT), 0.39% (LT) and 0.45% (LC).

Magnesium. The concentrations of Mg were fluctuating only slightly above the limit of deficiency (0.06%) during all three periods of investigation. The highest concentrations of Mg were found in 2001: 0.08% (AT), 0.08% (LT) and 0.09% (LC).

Table 5. Dry mass concentrations of macroelements and the limits of deficiency in spruce needles (in %)

		N	P	K	Ca	Mg	S
Limit of deficiency		1.2	0.1	0.35	0.15	0.06	0.07
1996	AT	1.38	0.21	0.54	0.47	0.07	0.15
	LT	1.28	0.18	0.48	0.41	0.06	0.12
	LC	1.97	0.18	0.49	0.41	0.07	0.13
2001	AT	1.64	0.19	0.65	0.43	0.08	0.13
	LT	1.57	0.17	0.64	0.40	0.08	0.13
	LC	1.71	0.18	0.68	0.38	0.09	0.11
2002	AT	1.32	0.12	0.45	0.46	0.07	0.14
	LT	1.39	0.11	0.44	0.39	0.07	0.16
	LC	1.42	0.12	0.46	0.45	0.07	0.11

Table 6. Foliar nutrient ratios in compared treatments and intervals of normal or adequate nutrient ratios

Nutrient ratios		N/P	N/K	N/Ca	N/Mg
Interval of normal or adequate nutrient ratio		6.0–17.0	1.3–4.9	2.0–11.3	8.0–28.3
1996	AT	6.73	2.58	2.94	19.30
	LT	7.11	2.67	3.12	20.65
	LC	10.75	4.02	4.84	27.62
2001	AT	8.78	2.54	3.82	19.77
	LT	9.23	2.48	3.98	18.74
	LC	9.74	2.52	4.55	19.77
2002	AT	10.91	2.93	2.87	19.42
	LT	12.55	3.17	3.57	20.80
	LC	11.92	3.08	3.15	19.97

The ratios are derived from original (not rounded) concentration values and then they were rounded to one decimal place. The seeming inconsistencies between Table 5 and Table 6 result from the fact that concentration values in Table 5 are rounded to improve its clarity

Sulphur. Between 1996 and 2002 the S concentrations in the AT and LC slightly decreased while they increased in the LT.

Nutrient ratios. As for the N/P ratio, the values close to the deficiency limit occurred in the AT and LT in 1996 (Table 6). Rather a low N/Ca ratio was recorded in the AT in 1996 and in 2002. Other values of nutrient ratios were within the intervals of normality.

DISCUSSION

Although a certain degree of stress is unavoidable under most planting conditions, it can be sometimes reduced by preparing a favourable planting site (Grossnickle 2005). The principle of initial fertilization is based on an effort to prepare a more favourable site in terms of available nutrients and soil chemistry. As for the type of fertilizers and form of application, Jacobs et al. (2005) stressed the importance of avoiding the use of quick-release fertilizers on forest sites and suggested that the application to the planting hole might be a useful alternative to broadcast fertilizing. According to Saarsalmi and-Mälkönen (2001) slow-release combined fertilizers provide new possibilities for the management of soil nutritional status and alleviation of soil acidification.

In terms of the growth rate, the spruces in our experiment responded to initial fertilization positively (Tables 2–4) although differences from the control were not always significant. As for mortality, the results are discussed in the text below. In a paper on Norway spruce by Kuneš (2003) (plantation was established at the same locality in 1991; 1 kg of dolomitic limestone was applied per tree) an even greater positive effect of liming was reported than that in our study. On the other hand, in a study conducted by Kateb et al. (2004) in the Krušné hory Mts. the vitality of Norway spruce seedlings was not improved by liming or other amelioration techniques and was not negatively affected by the high soil acidity. Balcar and Kacálek (2008) in the Jizerské hory Mts. reported a slightly negative influence of dolomitic limestone on the growth of silver fir (dosage and amendments were identical to those used in our experiment). In the same study, amphibolite treatment contributed to higher increments, which is in compliance with our results. Thus, the findings seem rather discrepant, nonetheless, the discrepancy or inconclusiveness of fertilization or liming effects was recorded also elsewhere in Europe (Jandl 1993; Nilsen 2001; Vejre et al. 2001) and in the world (Austin, Strand 1960).

Since there are many factors influencing the performance and vitality of young tree plantations established under forest conditions, it is not always possible to predict the effects of fertilization. Young trees on the extensive clear-cut tracts usually suffer not only from air pollution, acid soil and nutrient deficiency but also from harsh microclimatic conditions. The climatic conditions may sometimes limit the positive effect of fertilization on the planted trees (Kuneš 2003). In our experiment, the application of limestone and amphibolite contributed to higher absolute heights of the fertilized trees and partially increased the stem base diameter (Fig. 1, Table 3).

The trees of the AT overcame the post-planting shock, associated with height growth deceleration, in the shortest time (Fig. 1). It is obvious that the trees of the LT and AT were positively supported by the amelioration. Our results are in line with general conclusions presented by Kuneš (2003), who reported that the application of basic amendments on an acidic site can expedite growth revival after planting. Also Podrázský (2001) documented the positive effect of liming on the young tree plantations in the first years after planting.

The significantly slower growth of the individuals on the top of the ridge (UC) as compared to the site on the slope (LC), (Table 2), might be ascribed to a more extreme environment on the summit of the ridge in terms of soil conditions (peat podzol vs. mountain humus podzol) and microclimate. It is worth reminding that the LC and UC are situated within a short distance from each other (ca 150 m).

The positive effect of the amelioration was recorded in the values of stem base diameter (Table 3). Since the slenderness (h/d) ratios were comparable (40.6–41.0), the applied fertilization (at least from the h/d viewpoint) did not influence the static stability of the spruce stand.

From the comparison of mensurational characteristics (height and height increment, crown diameter and stem base diameter) between the LC, UC and the ameliorated treatments (Fig. 1 and Tables 2–4), we can conclude that the forest site variability could play a comparably important or even greater role in influencing the growth performance of spruces than the effects of fertilizing or liming. That is to say, because the differences between the environmentally more exposed UC and less exposed LC were comparably great (Table 3) or greater (Table 2, Fig 1) than the differences among the fertilized treatments and their respective LC.

As for mortality, the situation seems rather different; the mortality rates of both the LC and UC were comparable and considerably higher than the rates recorded in the ameliorated treatments. Nonetheless, the sharp upswing in mortality in the LC immediately after planting (1994) might have been caused also by other factors than only by the forest site variability (e.g. by improper outplanting or planting stock manipulation), because the post-planting shock often manifests itself to full extent no sooner than in the second year after planting. Moreover, the UC is more prone to suffer from post-planting shock than the LC. Furthermore, if the first year's upswing in mortality was excluded, the mortality rate in the LC would show the analogous dynamics as the rates recorded in the fertilized treatments while in the UC the sharp increase in mortality rate had been rather postponed and then it was lasting for several years.

On the basis of the chemical analysis of the assimilatory apparatus we can conclude that the macronutrient concentrations in all three treatments in the reference years (1996, 2001, 2002) did not decrease under the chosen deficiency limits. Nonetheless, in the case of P the concentrations were continually decreasing towards the limit of deficiency. Phosphorus is generally considered as a deficient macronutrient in the Jizerské hory Mts. (Špulák 2009; Kuneš et al. 2011).

In the first years after the establishing of the experiment the application of basic ameliorants could have negatively influenced the soil N dynamics and subsequently the availability of N for trees. Undesirable changes in the dynamics of soil N after liming (nitrogen losses in the surface layer of the limed plot caused by leaching) were described for example by Kreutzer (1995) and Nilsson et al. (2001). In further years (2001 and 2002) the differences in the N concentrations among all three treatments showed smaller differences.

In general the annual variability in the elemental composition of foliage played a more important role than differences between treatments. A dilution effect could further complicate the interpretation of the nutritional status after fertilization. A dilution effect after the initial fertilization of plantations was described e.g. by Óskarsson et al. (2006). Similarly, in comparable studies conducted at the same locality (Kuneš et al. 2004a, 2009) the effects of pulverised basic rocks applied at planting were evident in growth performance and survival of alder and spruce and were not conclusively reflected in the chemical composition of the assimilatory apparatus.

The values of the nutrient ratios ranged mainly within the interval of normal or adequate values. According to the classification by De Vries et al. (1998), the N/P ratios in the AT and LT fluctuated closely above the limit of deficiency in 1996. In the following years the N/P ratio increased and got into the interval of normal values. On the one hand it was a result of increased foliar N concentrations compared to the state in 1996, nonetheless, on the other hand it was also a reflection of decreasing P concentrations in foliage, which is a highly undesirable tendency. The concentrations of nutrients and nutrient ratios, therefore, should be contemplated simultaneously in order to be correctly interpreted. In 1996 in the LC the N/Mg ratio approached the upper limit of normal values. Higher N/Mg can indicate low Mg concentration in the needles (see Table 5). Lomský et al. (2011) recommended adjusting the N/Mg ratio to 8-25 for the Norway spruce stands in the region, which would mean even a closer approach to the upper limit of normal values in the LC.

CONCLUSIONS

The following conclusions can be drawn on the basis of our results:

– application of amphibolite significantly reduced the mortality rate, improved the height increments as well as the absolute heights and mean stem base diameter. The positive effect of limestone on mortality reduction was observable in the course of the first ten years. The application of limestone had an analogous positive effect on the growth of height and stem base of trees as the amphibolite application did, nonetheless, towards the end of the reference period the differences between LT and its respective LC ceased to be significant. Therefore, the use of amphibolite seems to be more effective than liming in the medium to long-term horizon,
– the site variability could play a significant role in influencing the growth performance of spruces even in a small forest area,
– temporarily lower N concentration was recorded in the fertilized treatments (AT and LT) in comparison with their respective control (LC). The concentration of P was low and decreased to the limit of deficiency in all treatments, P seems to be the most limiting macroelement in the area.

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Corresponding author
Ing. Tereza Koňasová, Czech University of Life Sciences Prague, Faculty of Forestry and Wood Sciences,
165 21 Prague 6-Suchdol, Czech Republic
e-mail: tereza.konasova@gmail.com