Growth and health state of silver fir (*Abies alba* Mill.) in the ridge area of the Jizerské hory Mts.

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ABSTRACT: The silver fir was planted under mountain conditions in order to reveal its response to the addition of finely ground rocks (limestone and amphibolite) mixed with soil into the planting holes. The results document that the increments of the plantations fertilised with amphibolite were higher by 25% on average than those of the control plantations while the increments of the plantations treated with dolomitic limestone were lower by 13%. Generally, as concerns both the plantations with the application of ground rocks and the control ones, the development of the fir plantations in 1994–2007 is considered successful. As the damage by climatic stresses has gradually diminished, the number of dead trees has been decreasing and the height increments have been increasing in the last years, therefore a positive development is to be expected also in future.

Keywords: silver fir; *Abies alba* Mill.; artificial regeneration; chemical amelioration

The silver fir (*Abies alba* Mill.) belongs to the most important tree species in the forests of the Czech Republic, its original representation in the area of the Jizerské hory Mts. having been ca 19% (Vacek et al. 2003). Its natural occurrence in the Jizerské hory Mts. ranges from the beech with oak Forest Altitudinal Zone (FAZ) to the spruce FAZ, i.e. up to the altitude of about 1,000 m above sea level, while the optimum of occurrence lies in the beech with fir FAZ at an altitude from 480 to 590 m a.s.l. Besides an economic effect, the fir also fulfils ecological functions and therefore it belongs to the ameliorative and stabilising tree species (OPRL 1999). For its importance, the silver fir was included in a planting experiment situated on the ridge, because it is considered as a suitable species for mid to higher altitudes (sufficient amount of precipitation) under the conditions of a decreased sulphur dioxide load (Eisenhauer et al. 2003). Therefore, the fir plots were established to test its prosperity and use in new forest stands in localities formerly afflicted by a high pollution load in the period from the mid-seventies to the mid-nineties of the last century.

MATERIAL AND METHODS

Research plot (RP) was established on a clearing due to salvage felling (an area of about 20 ha) in the upper part of the south-western slope as a locality representing very adverse growth conditions of the summit area of the mountains. The locality is situated at an altitude of 950 to 980 m, 50°49'34''NL and 15°21'19''EL. According to Forest Management Institute (ÚHÚL) classification, the site of RP belongs to acidic spruce forest (FAZ 8 K, OPRL 1999) which is considered as a typical site in the summit parts of the Jizerské hory Mts., though the investigation of the climate (1994–2007, see Results and Discussion) reveals milder conditions being expected in lower sites (acidic spruce with beech stands, FAZ 7 K, OPRL 1999). Soil type is Ferro-Humic Podzol (FAO), the parent rock is biotitic granite.

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Five-year old, bare-rooted plants of the silver fir were planted within the research plot in the spring of 1994, at a spacing of 2 × 1 m onto square parcels 10 × 10 m in size (i.e. 50 individuals per parcel). The average initial height of the fir plantations was 18 cm. To minimise the influence of random differences on the growth conditions (soil conditions, microrelief, etc.), the plantings on the research plot were distributed into three blocks – replications, each replication included all variants; i.e. 450 fir plantings were planted altogether (control + ameliorated). The tests of the potential support to the vitality of the fir plantations by means of ameliorating measures were a part of the experiment. A part of the plantings was standard without soil amelioration treatment (control), in another part finely ground dolomitic limestone and finely ground amphibolite were added into the soil (Balcar et al. 2005).

(Note: Dolomitic limestone of Horní Lánov origin contained 21.5% Ca and 11.3% Mg and consisted of these particle-size fractions: 57.5% of particles smaller than 0.2 mm, 20.4% of particles 0.2–0.5 mm in diameter, 16.3% of particles 0.5–1.0 mm in diameter, and 5.8% particles larger than 1.0 mm. Amphibolite of Markovice origin contained 7.9% Ca, 4.8% Mg, 0.8% K, and 0.1% P, and its particle-size structure was as follows: 42% of particles smaller than 0.05 mm, 53% of particles 0.50–0.25 mm in diameter, and 5% of particles larger than 0.25 mm.) Both these ground rocks were mixed with soil in the hole during planting, dolomitic limestone and amphibolite were applied in the amounts of 1 kg and 2 kg per plant, respectively (Balcar, Podrázský 1995; Podrázský, Balcar 1996; Kuneš et al. 2004). The amount of limestone was chosen based on previous positive experience with such ameliorative material added to support the growth of plantings near Trutnov (Tesař 1968), in the Orlické hory Mts. and Jizerské hory Mts. (Podrázský 1994). The dose of amphibolite was higher since the nutrient release and subsequent influence upon soil acidity were expected to be delayed compared to limestone.

Health state of plantings – the occurrence of the damage symptoms and mortality – was checked every year in spring. If the frequency of the damage symptoms was higher (damage to foliage due to ground frost, etc.), the spring check was repeated, and the proportion of damaged needles was estimated. The second check of the health state combined with the **measuring of the heights** of all tested trees was carried out after the growth termination at the beginning of autumn. The height growth was evaluated according to the parameters of all living fir individuals in 2007 and according to 20% of the highest individuals to avoid an undesirable distortion of the

Table 1. Average monthly air temperatures from July 1997 to June 2007 registered by the NOEL 2000 station on Jizerka research plot (°C)

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	I–XII	V–X
1996							12.0	14.0	5.9	6.1	0.9	–7.0		
1997	–4.0	–2.0	0.1	0.7	9.1	13.0	13.0	16.0	10.0	2.3	0.0	–2.0	4.7	10.6
1998	–2.0	0.0	–2.0	5.7	9.8	13.0	13.0	13.0	9.3	4.0	–3.0	–4.0	4.7	10.4
1999	–3.0	–5.0	0.8	4.8	9.8	11.0	15.0	14.0	14.0	4.7	–1.0	–4.0	5.1	11.4
2000	–5.0	–2.0	–0.7	7.5	12.0	13.7	11.3	15.4	10.0	8.4	3.0	–1.0	6.1	11.8
2001	–3.6	–2.4	–0.7	3.2	11.1	10.6	15.0	15.6	8.0	9.3	–1.1	–5.2	5.0	11.6
2002	–2.3	0.2	1.1	4.1	12.8	13.4	14.9	16.4	9.1	3.1	1.5	–5.2	5.8	11.6
2003	–5.4	–5.2	0.4	3.2	11.4	15.3	14.6	16.5	10.6	1.1	2.9	–2.7	5.2	11.6
2004	–6.7	–3.3	–0.8	5.1	7.1	11.3	13.3	14.8	9.7	6.3	0.0	–2.7	4.5	10.4
2005	–3.7	–5.7	–2.7	5.5	9.6	12.2	14.7	12.7	12.0	7.3	–0.7	–3.9	4.8	11.4
2006	–5.2	–6.3	–3.6	4.5	9.2	14.1	19.6	12.0	13.4	8.0	2.7	0.0	5.7	12.7
2007	–1.2	–1.3	2.2	7.7	11.3	14.1	13.6	13.8	7.5					
Average	–3.8	–3.0	–0.5	4.7	10.3	12.9	14.2	14.5	10.0	5.5	0.5	–3.4	5.1	11.2

The values of IV and V 1997 were calculated by interpolation according to the nearest station of Czech Hydrometeorological Institute (CHMI) – Souš results – average values – by differences in mortality between the planting variants and by the survival of declining individuals with the growth stagnation.

Nutrient state of the tested plantings was indicated by the results of chemical analyses of needles. Mixed samples of needles were taken from the upper parts of the crown in 10 trees on each parcel (replication), i.e. from 30 individuals. The analyses were done in Tomáš Laboratory in Opočno Research Station in accordance with the standardised methods (Zbíral 1994). The plots were fenced to protect the plantations against the game (deer and hare) browsing.

As for the **climate conditions**, precipitation is measured with a conventional rain gauge all over the year, and the snow cover thickness is measured in weekly exposure periods. Since 1996, air temperatures at a height of 200 cm and 30 cm above the ground have been registered and soil temperatures at a depth of 20 cm in one-hour intervals have been recorded using a NOEL 2000 automated station located directly on the research plot. The station also records the rainfall in one-hour intervals and soil moisture content in daily intervals.

The differences between the biometric parameters in the planting variants and blocks were tested using *t*-test, confidence intervals, and two-factor analysis of variance ANOVA (Meloun, Militký 2002).

RESULTS AND DISCUSSION

Average annual temperatures at a height of 200 cm above the ground in the period of measurement (July 1996–October 2007) ranged from 4.5°C to 6.1°C, the average being 5.1°C. Temperatures in one-hour intervals ranged from –21.6°C to 31.6°C. In the growing season (May to October), the average of monthly temperatures was 11.2°C (Tables 1 and 2).

The fluctuations of surface temperatures (+30 cm above the ground) in the dormant season (November–April) were diminished by the snow cover every year (Fig. 1). In the growing season (May–October), the average surface temperature (11.6°C) was higher by 3 tenths of a degree than the above-mentioned temperature at two metres above the ground, but the range of the means of extreme temperatures was substantially wider (the mean of maximum temperatures 32.5°C and that of minimum temperatures –4.6°C).

Annual precipitation amounts measured on Jizerka RP in the period of January 1994–September 2007 fluctuated in the range from 690 to 1,373 mm, and their average annual amount was 1,093 mm (Table 3). The rainfalls were the highest from June to September – with the month average of 130 mm, while the highest month rainfall amounts were recorded in July 1997 (527 mm) and in August 2006 (522 mm).

Based on continuous observations of the climate elements until September 2007, a conclusion was drawn about great differences from the expected parameters. The average annual air temperature (5.2°C) was markedly higher than the temperature anticipated for the given locality (4.0°C) with respect to the location in the Spruce Altitudinal Zone (OPRL

Table 2. Average monthly air temperatures and temperature extremes from July 1997 to June 2007 registered by the NOEL 2000 station on Jizerka research plot (°C)

Month	+200 cm above the ground			+30 cm above the ground		
	mean	maximum	minimum	mean	maximum	minimum
January	–3.8	11.4	–21.6	–1.8	12.2	–19.6
February	–3.0	12.7	–19.5	–0.8	12.4	–13.7
March	–0.5	16.4	–16.8	–0.1	16.5	–14.5
April	4.7	22.6	–10.6	4.6	26.4	–11.2
May	10.3	28.0	–2.5	10.8	31.2	–6.9
June	12.9	30.2	–0.1	13.4	34.8	–2.6
July	14.2	31.6	3.8	14.7	36.1	0.7
August	14.6	31.1	3.8	14.7	36.8	–1.0
September	10.2	24.6	–1.1	10.3	30.0	–5.4
October	5.5	22.0	–9.1	5.5	26.1	–12.6
November	0.5	15.0	–15.7	0.7	17.8	–13.2
December	–3.4	12.6	–19.6	–2.4	14.7	–18.5
Mean I–XII	5.2	21.5	–9.1	5.8	24.6	–9.9
Mean V–X	11.2	27.9	–0.9	11.6	32.5	–4.6

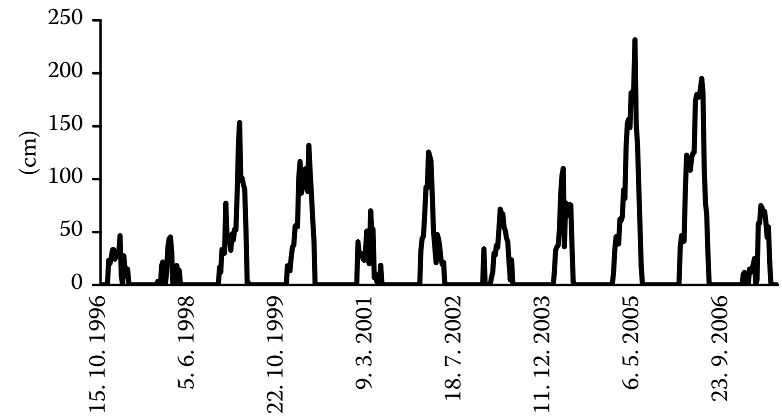

Fig. 1. Average snow cover thickness measured in weekly intervals on Jizerka RP from October 1996 to May 2007

1999; Vacek et al. 2003) as well as with respect to the data from previous measurements of Czech Hydrometeorological Institute (CHMI) (Slodičák et al. 2005). On the contrary, the average annual precipitation amount (1,093 mm) was lower than that anticipated (1,450 mm).

As expected, the tested plantations of the silver fir were damaged due to late ground frosts already in the first years after planting. In the research plot locality, flushing took place according to the air temperature in the given period usually from the end of May to the end of June, and new shoots were often damaged mainly by June frost episodes. Besides the flushing stage, the extent of damage expressed by the number of the damaged individuals was influenced by the value of air temperature drop in the ground layer and by the duration of frost episodes (Table 4). Especially in the first years after planting, repeated damage to newly flushed shoots slowed down the growth and led to the mortality of afflicted individuals. The damage by ground frost occurred only in the surface layer up to a height of 60–100 cm above the ground. The shoots above this height were not damaged, and therefore the ground frosts in the last years, when the majority of the shoots exceeded this height, did not significantly influence the overall vitality of the plantations any longer (Figs. 2 and 3).

Besides late frosts, the plantations of the silver fir suffered from desiccation of older year needles in early spring due to insolation and increased temperature of the air surface layer at low temperatures of soil mostly covered by snow. But the development of the plantations was not influenced by this type of damage very much. The high snow covers caused the top breakage and stem deformations in the fir plantations in the last two years. The numbers of the damaged individuals were relatively low – 1% of trees were damaged in 2005 and 2% in 2006, respectively,

Table 3. Average monthly precipitation amounts measured by the standard method on Jizerka research plot (mm)

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
1994	36	18	71	62	84	76	66	141	68	111	71	74	878
1995	257	63	164	95	89	104	78	131	114	10	49	20	1,174
1996	3	33	109	122	142	152	205	86	155	95	92	17	1,210
1997	6	60	43	73	154	82	527	75	35	152	26	63	1,296
1998	45	34	54	42	37	144	155	92	201	166	113	48	1,131
1999	42	61	40	32	63	121	138	40	66	150	28	47	828
2000	67	108	122	4	101	41	245	36	99	48	64	39	975
2001	49	55	57	72	59	156	213	66	277	50	101	69	1,224
2002	42	56	26	52	101	67	135	242	121	148	76	44	1,110
2003	102	26	31	44	40	25	100	30	66	135	20	71	690
2004	103	47	48	53	92	103	131	132	105	60	131	66	1,071
2005	88	82	70	21	101	178	134	169	116	23	54	131	1,166
2006	41	77	60	40	71	109	20	522	53	85	226	68	1,373
2007	144	101	63	3	107	100	145	86	187				
Mean	73	59	68	51	89	104	164	132	119	95	81	58	1,093

Fig. 2. Newly flushed shoots of silver fir damaged by late ground frost on Jizerka research plot in June 2005

Fig. 3. Detailed view of newly flushed shoots of silver fir damaged by late ground frost on Jizerka research plot in June 2005

which was insignificant for the development of the tested plantations.

The mortality of the silver fir experimental plantations on Jizerka research plot was lower than expected, in spite of the fact, that the plantings were situated on the margin of the tree species ecological amplitude (spruce altitudinal zone). About a quarter (28%) of the planted trees died in the first six years after planting, in the next seven years it was less than a tenth (9%, Table 5). Total mortality of the silver fir experimental plantations was 37% on average. The mortality of the control plantings was higher ca by 10% than that of the plantings treated with dolomitic limestone and amphibolite. But these differences also correspond to the differences between the planting replications, and so they are not considered as particularly important.

The dynamics of the height growth of the silver fir experimental plantings was evaluated on the basis of the results of the measurements of all trees living in 2007, and of the highest trees in 2007 (= 20% of the plants, i.e. the 10 highest trees per parcel, in total 30 individuals per planting variant). The results document a marked transplanting shock in the first six years (1994–1999) that slowed down the growth of these trees. The differences between the planting variants were relatively small and statistically insignificant at that time. Later on, there was a gradual increase in the height increments that were higher in the variant fertilised with amphibolite than in the control and limed variants in the period 2000–2004. The differences were statistically significant in certain years only. In the last three years (2005–2007), such a trend was not observed any more. The growth was the slowest in the variant with dolomitic limestone application, the increments having been on average lower by 11% than in the control variant,

Table 4. June minimum temperatures, late ground frosts, and the percentage of damaged individuals of silver fir on Jizerka RP

Year	Date of minimum temperature	Min. temperature at 30 cm above ground (°C)	Frost duration (h)	Damaged individuals (%)
1998	June 18th	0.7	0	0
1999	June 24th	–0.3	1	0
2000	June 1st	–0.8	5	87
2001	June 13th	–1.6	1	57
2002	June 1st	1.6	0	0
2003	June 14th	1.9	0	0
2004	June 27th	1.4	0	0
2005	June 2nd	–1.9	8	100
2006	June 2nd	–2.6	9	100
2007	June 1st	1.8	0	0

Table 5. Mortality of silver fir plantations 1994–2007 (%)

Period	Control	Limestone	Amphibolite	Mean
1994	2.1	8.8	6.0	5.6
1995	13.1	5.4	6.7	8.4
1996	4.8	2.7	2.0	3.2
1997	1.4	1.4	2.0	1.6
1998	9.7	4.1	5.4	6.4
1999	2.8	2.0	2.7	2.5
2000	0.0	1.4	1.3	0.9
2001	1.4	1.4	3.4	2.0
2002	3.4	2.7	0.0	2.1
2003	0.0	0.0	0.7	0.2
2004	0.0	0.7	0.0	0.2
2005	0.7	2.0	1.3	1.4
2006	0.0	0.0	0.7	0.2
2007	0.7	0.0	0.7	0.5
1994–2000	33.8	25.7	26.2	28.5
2001–2007	6.2	6.8	6.7	6.6
1994–2007	40.0	32.4	32.9	35.1

and lower by 23% than in the variant fertilised with amphibolite (6). Certain (expected) heterogeneity of the growth conditions in the locality of the research plot is documented by the differences in the growth of the tested plantings in replications in three blocks that amounted to 19% on average. The differences

Table 6. Basal height (h 1993) and height increments (ih 1994 ...) of all trees alive in 2007 and the highest 20% trees of silver fir plantations (cm)

	All trees alive in 2007				Highest 20% trees			
	C	L	A	mean	C	L	A	mean
h 1993	19.5a	18.5a	19.2a	19.1	25.3a	26.3a	26.4a	26.0
ih 1994	1.4a	1.7a	1.6a	1.5	1.8a	1.9a	1.8a	1.8
ih 1995	1.6a	3.2b	3.3b	2.7	1.5a	4.5b	3.6ab	3.2
ih 1996	4.0a	5.5b	6.6c	5.3	5.5a	7.3ab	7.6b	6.8
ih 1997	3.1a	3.1ab	3.8b	3.3	4.6a	4.8a	4.3a	4.6
ih 1998	4.2ab	3.9a	5.1b	4.4	5.4a	6.4a	6.7a	6.2
ih 1999	2.9a	2.7a	3.5a	3.0	3.8a	5.1a	5.2a	4.7
ih 2000	4.6b	2.3a	3.6a	3.5	7.7a	5.1a	7.1a	6.6
ih 2001	6.4ab	5.5a	7.9b	6.6	10.6a	9.9a	13.9a	11.5
ih 2002	9.2a	8.6a	14.1b	10.6	15.6a	16.5a	20.8a	17.6
ih 2003	10.5a	8.6a	14.4b	11.1	17.1a	14.9a	20.2a	17.4
ih 2004	9.6b	6.9a	12.5b	9.7	15.5a	15.2a	21.4a	17.4
ih 2005	7.3ab	4.9a	7.3b	6.5	11.7a	11.4a	13.2a	12.1
ih 2006	11.3ab	8.5a	12.1b	10.6	21.9a	17.7a	20.8a	20.1
ih 2007	14.6ab	11.5a	17.1b	14.4	26.4a	24.9a	28.7a	26.7
ih 1994–2000	21.8a	22.3a	27.3b	23.8	30.2a	35.1a	36.2a	33.9
ih 2001–2007	68.8b	54.7a	85.2c	69.6	118.8ab	110.5a	138.9b	122.7
ih 1994–2007	90.6b	76.9a	112.6c	93.4	149.0a	145.6a	175.1a	156.6

Plantation variants: C – control, L – limed, A – with amphibolite, statistically homogeneous groups (a, b, c) according to results of Kruskal-Wallis test (probability 95%)

between the height increments of the planting variants (control, amphibolite, limestone) and the increments in replications in 1994–1999 and 2000–2006 were confirmed by the computations of statistical confidences.

Based on the results of two-factor analysis of variance ANOVA for the height increments in 1994–2004, it is possible to state with the 20% of the highest trees that the different growth conditions tested by three planting replications contributed to the variance of the resultant values during the experiment (1994–2007) to a larger extent than the variants with different applications of ameliorative treatment (control, limestone, amphibolite).

The dynamics of the height growth of all individuals that were alive in 2007 on the research plot has a similar trend as the selected 20% of the highest trees (Table 6). In the sets of all trees that were alive in 2007, at the beginning of the experiment the height increments of the fir plantations after the application of amphibolite and dolomitic limestone were higher than in the control variant. Later on, the limestone-treated plantations slowed down their growth, and at present (2007) the total increments are lower by 13% on average than those in the control plantations. The amphibolite-treated plantations had a higher vitality also in the second half of the experiment (2000–2006) and their average increment is higher by 25% than that in the control plantation.

If compared with analogical experimental plantations, our results are comparable with the silver fir development in Lesní bouda locality in the Krkonoše Mts. (altitude 1,080 m a.s.l., Kriegel 2002), where the average six-year height increment was 22 cm. Contrary to the previous statement concerning the unsuitability of the fir in summit parts of the Czech mountains (Zatloukal 2001), the fir planted under the conditions of spruce with beech-spruce FAZ grew successfully in juvenile stage. The growth capacity of plantations in the mountain and foothills localities at lower altitudes with more favourable growth conditions was higher, e.g. in Fláje locality at an altitude of 800 m a.s.l. (Krušné hory Mts. – Kriegel, Bartoš 2004) or in Lanovka locality at the altitude of 520 m (Broumovská vrchovina upland – Balcar 1991).

On the Polish side of the Jizerské hory Mts., the performance of the silver fir plantations had been tested by Niemtur and Gazda (1999). On the experimental plot established in 1992 at the elevation of 950 m a.s.l., five-year mortality of the fir plantation was 26% and its average height was about 32 cm, thus their development was very similar to our control variant (five-year mortality 31%, height 32 cm, see Tables 5 and 6). A later experiment concerning the fir planted in the Polish Jizerské hory Mts. was published by Hawryś et al. (2004). Mean mortality of all planted firs (6 provenances) on the higher situated experimental series (960 m a.s.l.) exceeded

Table 7. Contents of main nutrients in one-year needles of silver fir and limits of optimum nutrition according to Bergmann (1988)

Element / Optimum limits	Variant	1996	2001	2002	2003	2004	2005	2006	Mean
N (%)	control	1.423	1.327	1.131	1.025	1.085	1.492	1.146	1.233
1.300	limestone	1.393	1.303	0.987	0.983	1.094	1.481	1.223	1.209
1.800	amphibolite	1.457	1.346	1.121	1.056	1.166	1.314	1.322	1.255
P (%)	control	0.208	0.160	0.101	0.100	0.110	0.129	0.109	0.131
0.130	limestone	0.220	0.177	0.110	0.090	0.100	0.123	0.098	0.131
0.350	amphibolite	0.213	0.159	0.105	0.110	0.106	0.111	0.107	0.130
K (%)	control	0.480	0.648	0.550	0.510	0.660	0.760	0.790	0.628
0.500	limestone	0.477	0.633	0.480	0.520	0.640	0.760	0.760	0.610
1.100	amphibolite	0.533	0.647	0.550	0.540	0.650	0.670	0.820	0.630
Ca (%)	control	0.455	0.453	0.590	0.540	0.540	0.370	0.620	0.510
0.400	limestone	0.503	0.397	0.510	0.600	0.740	0.440	0.570	0.537
1.200	amphibolite	0.590	0.397	0.530	0.600	0.650	0.560	0.640	0.567
Mg (%)	control	0.063	0.072	0.066	0.077	0.103	0.059	0.087	0.075
0.150	limestone	0.069	0.070	0.085	0.090	0.095	0.069	0.080	0.080
0.400	amphibolite	0.059	0.074	0.081	0.098	0.097	0.076	0.092	0.082

39% during the first four years after planting, on the series placed at a lower elevation (700 m a.s.l.) it was somewhat lower – 35%. Mean height increment from the second to the fourth growing season was 15.2 cm in the higher site and 18.6 cm in the lower one.

The nutrient state of the silver fir plantations was determined by analyses of one-year needle samples taken in autumn in 1999, 2001, 2002, 2003, 2004, and 2005 (Table 7). The comparison with the limit values of optimum nutrition (Bergmann 1988) shows that the supply of nitrogen and phosphorus was insufficient in 2002–2004. Among the planting variants, the lowest nitrogen level was determined in the plantation fertilised with dolomitic limestone, which had the slowest average growth in the given period. Potassium and calcium contents in needles were mostly in the limits of optimum nutrition, only in isolated cases they were slightly below this level. The supply of magnesium was markedly below the limit of optimum nutrition, without any explicit trend in the planting variants.

Unsufficient nutrient status in one-year needles of the silver fir caused by nitrogen, potassium and magnesium deficiency was also found by Hawryś et al. (2004). The criteria of deficiency used by him were similar to those used by Bergmann (1988), with the exception of potassium which was much higher (0.9% K), than that of Bergmann (0.5% K).

CONCLUSIONS

Based on the results of the investigations into the development of the silver fir plantations and the dynamics, of some climatic factors, these conclusions are drawn:

In the model area of the Middle Jizerský Ridge, which represents a summit part of the Jizerské hory Mts., in the period of our research investigations the air temperatures (average 5.2°C) were markedly higher than expected (below 4°C). On the contrary, annual precipitation amounts (average 1,093 mm) were always lower than the assumed long-term normal (above 1,450 mm).

Relatively favourable temperatures (contrary to the expectation) with frost extremes to –21.6°C were apparently only one of the causes of the successful growth and relatively low mortality of the experimental plantings of the silver fir established in a locality of clearing due to salvage felling. Even though the fir plantations were damaged by late ground frosts almost every year, nearly one half of the present number of trees (48%) overcame the critical height of their effect and they are not threatened by this factor any longer.

The applications of fertilisers in the form of amphibolite and finely ground dolomitic limestone influenced the growth of plantations, but they did not have any crucial effects on the overall prosperity of the plantations expressed by mortality recorded until now. The results document that the increments of the plantations fertilised with amphibolite were higher by 25% on average than those of the control plantations while the increments of the plantations treated with dolomitic limestone were lower by 13%. The negative influence of dolomitic limestone observed in the second half of the research period may be explained on the basis of the hypothesis published by Podrázský and Ulbrichová (2001), Podrázský (2003); the breakdown of soil organic matters is accelerated and the reserve of the available soil nutrients is reduced. This also explains the lowest (deficient) level of nitrogen supply in the limed variant that was proved by foliage analyses in 2002–2004.

In general, the hitherto development of the fir plantations in 1994–2007 is evaluated as successful; both of the plantations with the application of rock meals and of the control ones. As the damage by climatic stresses has gradually diminished, the number of dead trees has been decreasing and the height increments have been increasing in the last years, a positive development is to be expected also in the future. From the long-term aspect of the forest stand development, the hitherto eleven-year growth is only one of the time segments of the existence of the fir plantation and its prosperity – health state and vitality will therefore be examined and evaluated in the years to come.

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Present investigations on this research plot and the testing of prosperity of forest trees species including the silver fir in the ridge area of the Jizerské hory Mts.

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Růst a zdravotní stav jedle bělokoré (*Abies alba* Mill.) v hřebenové oblasti Jizerských hor

ABSTRAKT: Jedle bělokorá byla vysazena v horských podmínkách za účelem sledování reakce jedinců na dodání mletých horninových mouček (vápenec a amfibolit) do jamky. Výsledky dokládají, že varianta přihnojená amfibolitem vykazovala v průměru o 25 % vyšší přírůst proti kontrole, zatímco výsadba s aplikací dolomitického vápence vykazovala přírůst o 13 % nižší. Obecně – pokud se týká vývoje všech výsadeb s aplikací melioračních materiálů i kontroly – vývoj jedlových výsadeb v období 1994–2007 je považován za uspokojivý. V souvislosti s poklesem významu klimatického stresu se v poslední době mortalita snižuje a výškové přírůsty se zvyšují. Proto očekáváme další pokračování pozitivního vývoje výsadeb.

Klíčová slova: jedle bělokorá; *Abies alba* Mill.; umělá obnova; chemická meliorace

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