Cultivation of speckled alder under harsh mountain conditions

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ABSTRACT: The aims of the paper were as follows: (1) to assess the applicability of speckled alder for pioneer stands on the mountainous clear-cut tracts and (2) to evaluate the effects of slow-release fertilizer on the survival and growth of speckled alder under harsh environmental conditions. On the basis of seven-year results we can presume that speckled alder is a convenient pioneer species that can be cultivated on harsh mountain sites where the climatic extremes need to be alleviated and a layer of surface humus renewed. The initial slow-release fertilization is, nonetheless, highly desirable. As contrasted to the control the surface and planting hole applications of amendment reduced the total seven-year mortality rate by 9.5% and 20.1%, respectively, and the periodic annual height increment (2003–2009) was promoted by 47% and 59%, respectively. Analogous results were obtained when the values of basal stem diameter and crown diameter were compared. As for the method of application, the placement of the slow-release amendment in the planting holes seems to be more efficient mainly in terms of survival promoting. The surface application is, nonetheless, less laborious and also yielded satisfactory results.

Keywords: *Alnus incana*; grey alder; site amelioration; slow-acting amendments; biological amelioration

Mountain forest ecosystems in the northern part of the Czech Republic were heavily disturbed by extreme air-pollution stress combined with climatic stresses and biotic factors in the 1970's and 1980's (Dambrine et al. 1993; Vacek 2003).

The Jizerské hory Mts., the northernmost mountain complex in the country, are a typical seriously affected representative (Křeček, Hořická 2002). The overall area of clear-felled tracts after salvage cuttings in the most affected upper plateau of the Jizerské hory Mts. amounted to 12,000 ha. The situation in the region improved during the 1990's when the emissions of pollutants were considerably reduced (Hrkal et al. 2006) and the clear-cut tracts could be replanted again.

Nonetheless, the new generation of forests established after the air-pollution disaster needs to be diversified in terms of structure and species composition. The young post-disaster plantations are dominantly composed of Norway spruce (*Picea abies* [L.] Karst.) and also of allochthonous blue spruce (*Picea pungens* Engelman.), which was cultivated as a substitute species (Špulák, Dušek 2009) for its higher resistance to air pollution. At present,

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when the pollution disaster has receded, it is desirable to replace the exotic blue spruce with native trees.

The target species such as European beech (*Fagus sylvatica* L.) and Silver fir (*Abies alba* Mill.) should be reintroduced to the forests of the Jizerské hory Mts. (Balcar, Kacálek 2008a; Křeček, Hořická 2006). These species are nonetheless considerably more sensitive than spruce (Balcar, Kacálek 2008b) and show noticeably higher demands on the site. Previous attempts of forest practitioners to enrich the young spruce monocultures with sufficient admixture of beech and silver fir often failed.

Where diversification efforts failed or where blue spruce is to be converted, pioneer species are of great importance to form pioneer stands or groups desirable to alleviate microclimate extremes, restore the surface humus and nutrient cycling (Kuneš et al. 2007a; Podrázský et al. 2005).

As for autochthonous broadleaved pioneers, only birch (*Betula* sp.) and rowan (*Sorbus aucuparia* L.) are cultivated by forest practitioners on a larger scale on the upper parts of the mountains in the region. It is therefore highly desirable to extend our knowledge of the growth performance of other native pioneer species including possibilities of providing them the initial support under stress conditions.

The existence and growth of experimental alder plantations on the summit plain of the Jizerské hory Mts. suggest that speckled alder (*Alnus incana* Moench) belongs among the taxa which deserve a research in this regard.

The objectives of the present study are as follows:

(1) To assess the survival, growth performance and nutritional status of a young alder plantation under environmentally harsh conditions in the course of the initial seven years since planting.

(2) To evaluate the effects of a mixture containing crushed amphibolite and limestone that was applied as a support to alders at planting either into planting holes or as base dressing in circles around the alder seedlings.

METHODS

Site

An experimental plantation of speckled alder (*Alnus incana* Moench) was outplanted inside a game-proof enclosure on a formerly clear-felled tract in the Jizerské hory Mts., Northern Bohemia (50°49'N, 15°21'E). The site is located on the south-facing slope of the ridge at an altitude of 950–960 m a.s.l. The mean annual air temperature (1996–2007) on the site is 5.1°C and the mean annual precipitation (1994–2007) is 1,093 mm (Balcar, Kacálek 2008a). The bedrock was determined as biotitic granite, the soil as mountain humus podzol.

The herbaceous vegetation on the site is dominated by *Calamagrostis villosa* (Chaix) J.F. Gmelin. The average air SO_2, NO_2, O_3 concentrations in the period after air-pollution stress are 4 $\mu g \cdot m^{-3}$ (2005–2008), 5 $\mu g \cdot m^{-3}$ (2006–2008) and 102 $\mu g \cdot m^{-3}$ (2003–2008), respectively; see Balcar and Kacálek (2008a).

When alders were outplanted, the site was sparsely (ca 800 trees per ha) and more or less evenly colonized by small (h ~1.3 m) solitary spruces planted in 1994. At the outplanting time of alders, the site was free of harvest residuals and was densely colonized by grasses dominated by *Calamagrostis villosa* (Chaix) J.F. Gmelin. No weed control and soil surface preparation were applied.

Plantation

The experimental plantation was established with the use of one-year-old bare-rooted planting stock of autochthonous origin in May 2003. Altogether 350 alder seedlings were planted in seven subplots. Each subplot contained 50 trees spaced 1 × 2 m. In addition to the (1) control containing three subplots (150 seedlings), two fertilized treatments were used: (2) surface treatment (SUT) and (3) planting hole treatment (PHT), each consisting of two subplots (100 seedlings). In the ameliorated treatments a mixture of 0.5 kg of crushed limestone and 1.0 kg of pulverized amphibolite was applied per tree. In the SUT this mixture was applied as base dressing around alder seedlings in circles of approximately 0.5 m in diameter immediately after the trees had been planted. In the PHT the same amount of the mixture was incorporated into the soil inside planting holes (25 × 25 × 25 cm) at the outplanting of seedlings.

The materials used in the mixture (their chemical composition, grain size distribution and origin) are identical to those used in another alder experiment reported by Kuneš et al. (2009).

In situ measurements

The mortality and mensurational variables were recorded at the end of vegetation period. Tree heights were measured to the nearest 1 cm, crown diameters to the nearest 10 cm and basal stem diameters to the nearest 1 mm. The stem and crown diameters were measured twice in two perpendicular directions. The height increment is considered as a difference between two subsequent dates of measurement. It can thus also show negative values, e.g. if a tree was broken or bent by snow or rime. Under extreme conditions, where trees suffer from mechanical damage relatively frequently, this approach ensures that the continuity will be preserved between the annual height increment and the development of the real plantation height (Kuneš et al. 2009).

Nutritional status

The nutritional status of plantation was assessed on the basis of foliar macroelement concentrations in dry matter of assimilatory tissues. The criteria according to Kopinga and Van den Burg (1995) were used for the assessment.

A composite sample of leaves from each treatment was taken annually (except for 2005) in late August, when the aboveground parts of the trees had finished their active growth. The healthy fully developed leaves were pooled in the samples which were transported to the laboratory and dried at 70°C until constant weight. The total concentrations of N, P, K, Ca, Mg and S were then determined.

The applied chemical analytic methods were described by Zbíral (1994) in Czech. Therefore, a short introduction is provided.

One gram of the sample tissue was mineralized with sulphuric acid under the oxidizing effect of hydrogen peroxide (30% solution) until the pure mineralized substance was obtained. After cooling, the product of mineralization was transferred to a 100-ml volumetric flask, made to the volume with deionized water and shaken. The mixture was filtered using medium density filter paper, collected to the stock bottle and used for macroelement content analyses. The concentration of N was determined by distillation of ammonia ions into a volumetric solution of sulphuric acid. The concentration of phosphorus (P) was quantified by spectrophotometry using a Spekol 210 apparatus. Determination of potassium (K), calcium (Ca), and magnesium (Mg) was done using a Varian SpectrAA-400 Plus atomic absorption spectrophotometer. Potassium concentration was determined by flame emission photometry (FEP). The Ca and Mg contents were determined by atomic absorption spectroscopy (AAS).

The concentration of sulphur (S) was determined using the wet digestion of sample tissue with nitric and perchloric acids. The product of mineralization was diluted with deionized water and filtered. The filtrate was heated and barium sulphate was precipitated by the addition of barium chloride solution. The obtained solution was filtered again. The precipitate was carefully washed with boiling water, dried, ignited and weighed. From the registered weight the S content was calculated.

Statistical analysis

The mortality rates were assessed by means of a binomial test with subsequent multiple comparisons described e.g. by Anděl (1998).

Height increment, basal stem diameter and crown diameter were statistically analyzed using the Kruskal-Wallis procedure (heteroscedasticity of data) and post-hoc Nemeny's multiple comparison. The STATISTICA 8.0 software was used for this statistical procedure described in detail by Hill and Lewicki (2006).

The pooling of leaves into one composite sample per each treatment did not unfortunately allow assessing the variability inside the treatments and executing ANOVA or Kruskal-Wallis procedure for particular years. Nonetheless, the treatments were compared in a different way: trends of the N, P, K nutrition of plantations were evaluated using linear-regression models smoothing the macroelement concentrations recorded within a treatment in the years of sampling. For each macroelement and treatment, the existence of a significant divergence of the time axis and regression line representing development in macroelement concentration was examined. For each macroelement, a mutual parallelism of regression lines representing the compared treatments was also tested. The significance of downward trends in foliar Ca and Mg concentrations and their ratios to N (for their apparent nonlinearity) were tested using a power trend function $y = ax^b$ by finding the significant evidence that the b exponent of the function is a negative value. The methods were described by Anděl (1998) and were executed by S-PLUS 6.1 software. The 95% confidence level was chosen in all statistical tests. The size of the experiment was sufficient to make a relevant statistical analysis enabling the verification of our outcomes and conclusions. Some of our outcomes are supported by a similar alder experiment in the area reported by Kuneš et al. (2009).

Table 1. Total mortality (t. m.) and annual mortality (a. m.) rates in the control, surface (SUT) and planting hole (PHT) treatments during the studied period (2003–2009)

Treatment	Mortality (%)	Year						
		2003	2004	2005	2006	2007	2008	2009
Control	t. m.	7.4[a]	15.4[a]	19.5[a]	23.5[a]	32.9[b]	34.9[b]	38.3[b]
	a. m.	7.4	8.0	4.1	4.0	9.4	2.0	3.4
SUT	t. m.	3.0[a]	5.9[a]	13.9[a]	18.8[a]	23.8[ab]	24.8[ab]	27.7[ab]
	a. m.	3.0	2.9	8.0	4.9	5.0	1.0	2.9
PHT	t. m.	3.0[a]	8.1[a]	12.1[a]	13.1[a]	16.2[a]	16.2[a]	18.2[a]
	a. m.	3.0	5.1	4.0	1.0	3.1	0.0	2.0

t. m. – values in the columns followed by different letters are significantly different from each other at $\alpha = 0.05$

RESULTS

Mortality

Fertilizing with the mixture of crushed basic rocks reduced the mortality rate of alder in the initial years after planting (Table 1). The PHT was more effective than the SUT in this respect, although the difference between the ameliorated treatments was not significant. However, a significant difference in the total mortality rate was proved between the PHT and control from 2007 to the end of the reference period. While the total mortality rate in the PHT equalled 18.2% in 2009, in the control it was more than twice higher (38.3%). Although the total mortality rate of 27.7% (2009) registered in the SUT did not significantly differ from the mortality rate in the control, a positive effect on survival, though not as pronounced as in the PHT, was also visible.

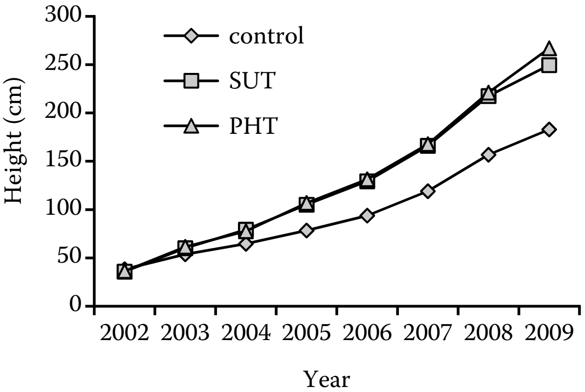

Fig. 1. Development of the mean height of trees in particular treatments in the studied period (2003–2009). The 2002 values express the height of trees at planting, which was realized in spring 2003 prior to the vegetation period

Growth

No stagnation in height growth was observed during the initial years after planting to the site (no post-planting shock) and irrespectively of the treatment the plantations began to increase their mean height annually (Fig. 1).

Nonetheless, height growth was markedly accelerated by applied fertilizing (Table 2). In 2009, the mean tree height values in the control, SUT and PHT were 183 cm, 249.5 cm and 267 cm, respectively. The mean height values in fertilized treatments were significantly higher than those in the control (Fig. 1).

The growth-stimulating effect of the applied amendment became significant already after the first growing period. The overall effect of the amendment application so far can be expressed using the values of periodic annual increment (2003–2009). The mean values of this characteristic in the SUT and PHT were higher than those in the control by 47% and 59%, respectively. Otherwise, the curves of annual height increment in all the compared treatments followed the same pattern of development. The growth rate noticeably accelerated in the second half of the studied period. The mean annual height increment values peaked in 2008, when they reached 37 cm, 51 cm and 53 cm in the control, SUT and PHT, respectively.

The PHT was slightly disadvantaged compared to the other two treatments as far as basal stem diameter of planted trees (2002) is concerned (Table 3). However, the stimulus by fertilizing into planting holes began to be evident already in 2004, when the PHT got ahead of the control. Since 2006 the PHT showed the highest basal stem values, though the differences from the SUT were small and insignificant. A much larger difference was record-

Table 2. Height increments in the control, surface (SUT) and planting hole (PHT) treatments in the studied period (2003–2009)

Treatment		Year							
		2003	2004	2005	2006	2007	2008	2009	2003–2009
Total *P*-value		0.0000	0.0000	0.0000	0.0003	0.0001	0.0002	0.0000	0.0000
Control	mean (cm)	15.6[a]	11.3[a]	14.0[a]	15.3[a]	25.0[a]	37.3[a]	26.2[a]	20.7[a]
	sd (cm)	10.46	11.50	17.25	13.71	20.62	27.16	31.59	13.36
SUT	mean (cm)	24.2[b]	19.6[b]	27.0[b]	23.9[b]	35.8[b]	51.0[b]	32.0[b]	30.5[b]
	sd (cm)	14.80	13.01	22.66	21.25	22.95	28.89	36.29	16.53
PHT	mean (cm)	23.4[b]	15.9[b]	28.9[b]	24.6[b]	36.4[b]	53.6[b]	45.8[b]	33.0[b]
	sd (cm)	11.44	15.19	21.01	14.31	16.46	27.47	37.74	12.80

Explanation for Tables 2–4: sd – denotes sample standard deviation, mean values in the columns followed by different letters are significantly different from each other at α = 0.05 (results of post-hoc multiple comparison by Nemeny's method)

Table 3. Values of the basal stem diameter in the control, surface (SUT) and planting hole (PHT) treatments in the studied period (2003–2009)

Treatment		Year					
		2002	2004	2006	2007	2008	2009
Total *P*-value		0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Control	mean (mm)	4.0[b]	5.8[a]	10.3[a]	14.1[a]	18.9[a]	24.0[a]
	sd (mm)	0.93	1.54	5.29	8.02	11.62	15.52
SUT	mean (mm)	4.2[b]	7.0[b]	15.2[b]	21.2[b]	26.2[b]	33.6[b]
	sd (mm)	0.95	2.01	8.21	10.34	14.02	16.91
PHT	mean (mm)	3.5[a]	6.7[b]	15.4[b]	21.4[b]	28.5[b]	34.9[b]
	sd (mm)	0.71	1.58	6.03	8.57	11.43	13.94

Table 4. Values of the crown diameter in the control, surface (SUT) and planting hole (PHT) treatments in the studied period (2003–2009)

Treatment		Year		
		2007	2008	2009
Total *P*-value		0.0000	0.0000	0.0001
Control	mean (cm)	54[a]	79[a]	104[a]
	sd (cm)	38.9	57.4	77.7
SUT	mean (cm)	81[b]	108[b]	133[b]
	sd (cm)	44.7	57.2	66.3
PHT	mean (cm)	89[b]	123[b]	147[b]
	sd (cm)	38.0	48.8	58.0

ed between both fertilized treatments on the one hand and the control on the other hand. In 2009 the mean basal stem diameters in the SUT and PHT were by 40% and 45% higher than those in the control, respectively.

The comparison of the crown diameter values (Table 4) yielded analogous results as that of stem basal diameter. Since 2007 the PHT showed the highest values, though the differences from the SUT were not significant. Significant differences, however, were recorded between both fertilized treatments on the one hand and the control on the other hand in all the studied years. In 2009 the values of crown diameter in the SUT and PHT exceeded the crown diameter in the control by 28% and 41%, respectively.

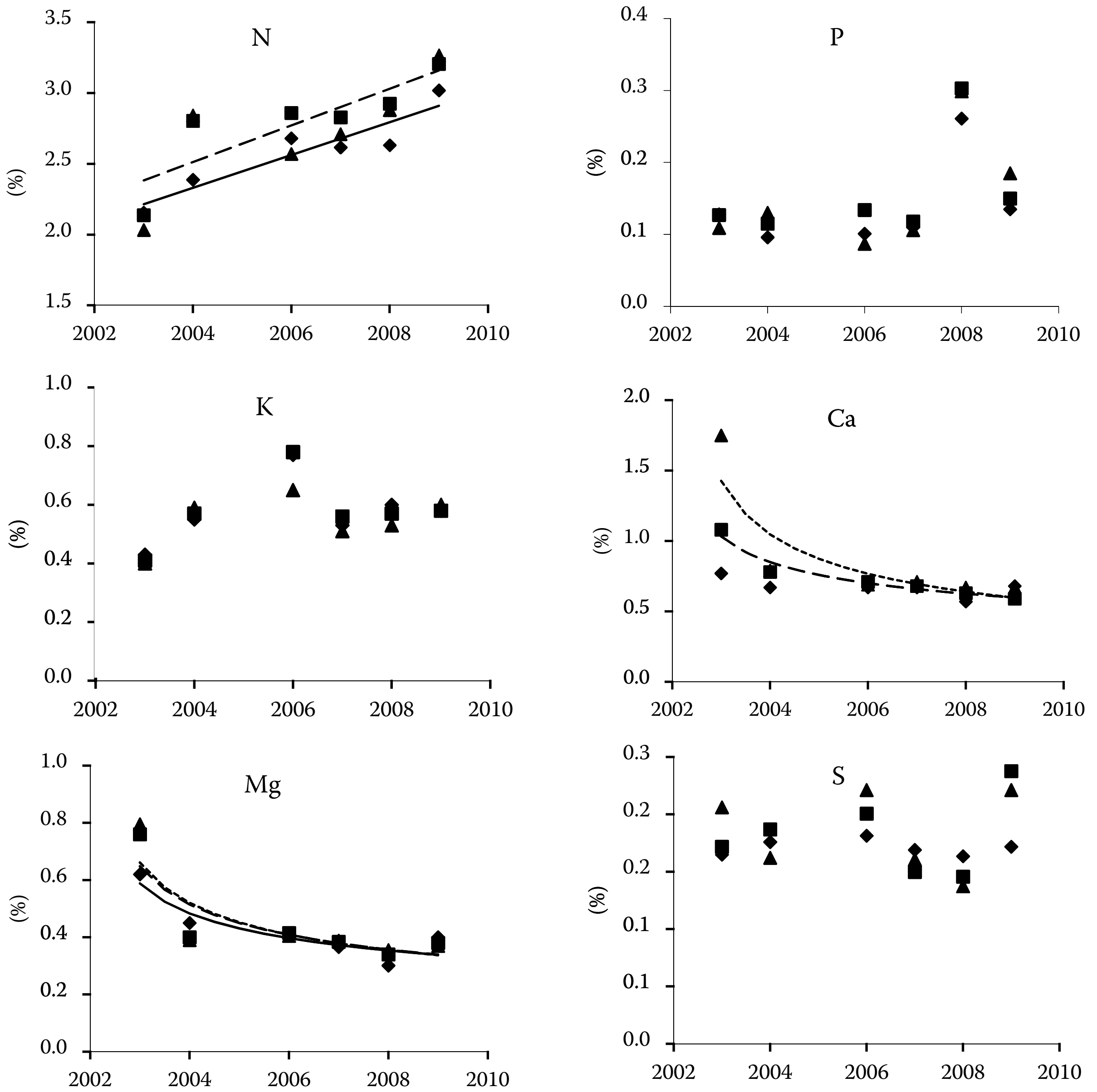

Fig. 2. Dry-mass concentrations of macroelements in leaves from the control, surface (SUT) and planting hole (PHT) treatments. The trends are depicted if they have been proved significant (P-level = 0.05)

Nutritional status

Despite some fluctuations, the N concentrations in all treatments successively grew from low to normal (adequate) values (Fig. 2). In 2009, the foliar N concentrations even attained an optimal level (> 3%) in the fertilized treatments as well as in the control. Significantly upward linear trends in the foliar N concentrations (2003–2009) were revealed in the control and SUT (P-values 0.01 and 0.03, respectively). In the PHT, the trend was just short of being significantly rising (P-value 0.06). No significant divergence of regression lines smoothing the N concentration values was found out in the compared treatments.

Between 2003 and 2007, irrespectively of the treatment the foliar P concentrations indicated a low P supply often on the verge of deficiency (< 0.1%). In 2008 a sharp rise was recorded in all three treatments bringing the P concentrations to the luxurious level of 0.26% and 0.30% in the control and both fertilized treatments, respectively. Then, in 2009, the values declined again; they however remained on a slightly elevated level as compared to concentrations in the initial stage of plantation. In 2008 and 2009 the P concentrations registered in the fertilized treatments were slightly to moderately higher than in the control. No significant (upward or downward) trends in the P status were recognized.

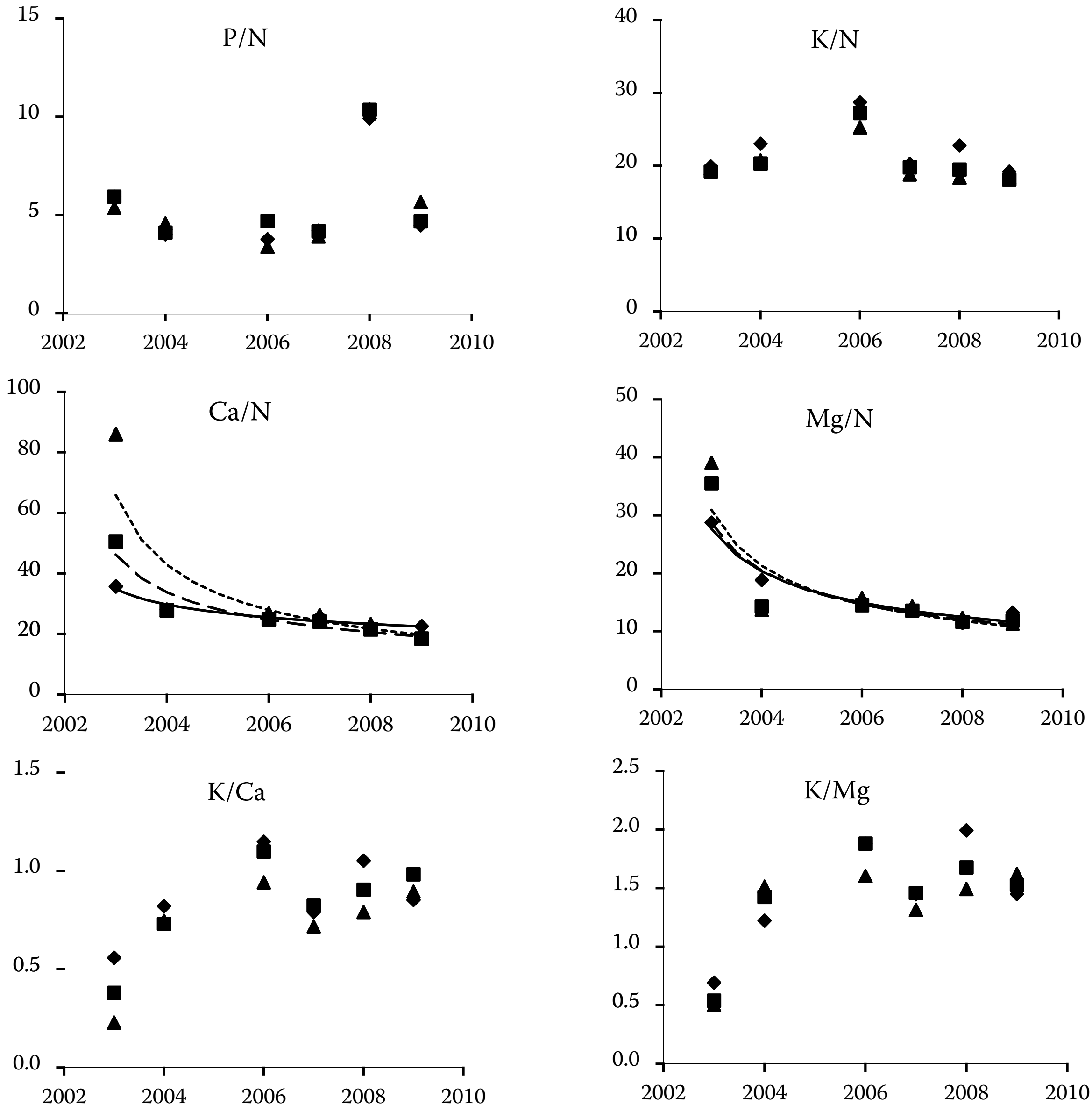

Fig. 3. Ratios of macroelements (their dry-mass concentrations) in leaves from the control, surface (SUT) and planting hole (PHT) treatments. The trends are depicted if they have been proved significant (P-level = 0.05)

The lowest K concentrations were recorded in 2003, when K supply was presumably on the verge of deficiency (< 0.4%). Afterwards the K supply somewhat improved and the recorded values slightly increased, nonetheless, the K concentrations remained in all three treatments mostly in the range indicating low K supply (0.4–0.6%). No significant (upward or downward) linear trends in the K status (2003–2009) were recognized in any of the compared treatments.

There was a striking difference in Ca concentrations among the treatments after the initial growing season. The Ca concentration in the PHT (1.75%) was more than twice as high as that in the control (0.77%) in 2003; a markedly increased Ca concentration (1.08%) was also registered in the SUT. A sharp drop in the fertilized treatments and a slight decrease in the control occurred in 2004. From 2006 onwards the differences among the treatments were marginal and the foliar concentrations ranged between 0.71% and 0.57%. To some extent an analogous pattern of development was observed in Mg concentrations although there was a marginal initial difference between the fertilized treatments in 2003 and a noticeable decline after 2003 was recorded not only in the fertilized treatments but also in the control. Nonetheless, the foliar Mg concentrations remained safely in the range of optimal Mg supply (> 0.25%).

A significantly downward trend of Ca concentrations (P-value = 0.0004 and 0.0160, respectively) was recorded in the SUT and PHT. As for Mg, a significantly downward trend was found out in all three treatments (*P*-values for control, SUT and PHT were 0.0209, 0.0223 and 0.0271, respectively).

The S concentrations in the fertilized treatments fluctuated considerably more than those in the control. In all three treatments the foliar S concentrations were elevated (they often exceeded 0.16%, occasionally even 0.20). No significant (upward or downward) linear trends in the S status were recognized in any of the compared treatments between 2003 and 2009. No significant mutual divergence of regression lines smoothing S concentrations in the compared treatments was found out.

The P/N ratios (Fig. 3) often below 5/100 indicated that the P supply of alders was not fully stabilized. The K/N concentrations below 25/100 in all three treatments indicated that the K supply was another limiting factor. On the other hand, the Ca/N and Mg/N ratios in all three treatments documented luxurious Ca and Mg nutrition, respectively, although there were rapidly and significantly decreasing trends. The K/Ca ratios frequently below 1.0 suggest a possibility of insufficient K supply as well as adequate Ca supply in all three treatments. Similarly, the K/Mg ratios signal plentiful Mg supply as compared to limited K supply.

DISCUSSION

Mortality

Fertilization was able to reduce the mortality rate of speckled alder growing under harsh environmental conditions. It seems that initial fertilization can partially compensate for the harshness of an environment in some cases, which was documented in the same locality e.g. on spruce (Kuneš 2003). Significant positive results of fertilization on the initial survival of forest plantation were also reported e.g. by Óskarsson et al. (2006).

In order to augment the survival it is essential to apply amendments at planting, because young trees are most stressed in the first years after planting. Kuneš et al. (2009) assessed the survival of another speckled alder plantation growing on a harsh site where, however, the amendment was applied two years after planting. The fertilization reported by Kuneš et al. (2009) improved the growth, nevertheless, difference in mortality rate between the control and fertilized treatments remained negligible, because most plants died prior to fertilizing.

As far as the mortality reduction, the application of the amendment into planting holes proved to be more effective probably because most of the slow-release amendment got immediately in the rhizosphere of newly planted trees. Slow-release fertilization into planting holes eliminates nutrient losses, and minimizes the potential advantage of competing vegetation (Austin, Strand 1960).

Growth

The periodic annual height increment (2003–2009) recorded in the PHT was slightly higher than that in the SUT, probably thanks to the application of nutrients (in the PHT) directly to roots of planted trees. Nonetheless, this difference is minor as contrasted to a difference between the fertilized treatments and the control. As for the height growth, the effects of both methods of amendment application are comparable.

Most of the fine roots of trees are located in the uppermost soil layer (Perry 1982) and alder is no exception (Uri et al. 2009). Thus, if the amendment is sufficiently slow-acting and thereby a time is provided for the roots of plants to colonize the soil, the surface application around trees may be relatively efficient. It should be noted that the tree-grass interaction prior to canopy closure rather complicates the prediction of tree response to base dressing (Struve 2002). However, in our case the amendment was applied to relatively small patches around seedlings and the grass sward was disturbed by planting at least temporarily.

On mountain clear-cut tracts rapid height growth in the initial years acts against mortality because it sooner gets the terminal leaders of trees above the zone of ground frosts and competing weeds. The height growth promoted by fertilization must be in balance with adequate growth in stem thickness. For this reason it is important that the ratios between tree height and stem base diameter remained similar for all three treatments ranging between 74.2 (SUT) and 76.5 (PHT).

As it is apparent from the crown diameter values (Table 3), fertilization promoted the canopy formation. Although the alder crowns are much less dense compared to spruce, they can provide essential shading and potential shelter for more sensitive target species. Moreover, the bigger the crowns, the larger the amount of litter produced annually and supplied to the soil.

Miller (1981) stated that fertilization is generally beneficial to trees, not to the site. Our situation, however, is rather specific. By fertilization we try to promote the growth, survival and vigour of small pioneer stands on the most degraded sites.

Through the small prosperous pioneer stands we intend to achieve the amelioration of a site (microclimatic shelter by canopy, N-rich litter input, mechanical protection against moving snow on the slopes etc.).

Inside such pioneer stands it will be easier to reintroduce more sensitive target species, such as beech or silver fir that prefer a shelter by the older existing stand (Balcar, Kacálek 2008b) and have higher soil requirements than pioneer trees.

Nutritional status

The increasing N concentration in dry mass of alder leaves indicates the adaptation of alder plantation to the site (improving N fixation efficiency) as well as persisting N deposition. According to Ingestad (1980), the N_2 fixation ability alone, without addition of mineral N, is sufficient for an almost optimal level of N. Similarly, Chambers et al. (2004) mentioned a nearly complete reliance of alder on N_2 fixation. In general, the proportion of atmosphere-derived N in alder nutrition ranges between 70% and almost 100% (Hurd et al. 2001; Myrold, Huss-Danell 2003).

The P supply influences N fixation and thus the growth of speckled alder (Hytönen, Saarsalmi 2009). According to Kopinga and Van den Burg (1995), a general estimate for the sufficient ratio of N/P in leaves of broadleaved trees is 100N/5–10P. The P demand of alder is, however, higher. Ingestad (1981) reported that the optimal nutrient ratio required by speckled alder is 100N/18P. Analogously, Hytönen et al. (1996) registered a higher P concentration in the biomass of speckled alder compared to downy birch. The P concentrations recorded in our study indicate that the P supply is limited on the site. Similar conclusions based on P availability in the area were published by Špulák and Dušek (2009). The P content upswing in 2008 might be a random deviation although it is too early to state it with certainty because the P concentrations in 2009 were still detectably higher as compared to those before 2008.

Potassium concentration in the assimilatory apparatus of alder is low. Its ratio to N, mostly fluctuating below 100N/25K, is insufficient using the limits for broadleaves estimated by Kopinga and Van den Burg (1995). The N/K ratio is also much below the optimal level of 100N/50K for alder reported by Ingestad (1981). The limited K supply is in accordance with findings from another alder plantation on the site (Kuneš et al. 2009).

The high Ca and Mg concentrations in the fertilized treatments after the initial growing period clearly show the effect of the amendment and its fading in the subsequent years. The relatively stabilized normal to optimal Ca and Mg foliar concentrations in all three treatments might reflect the areal liming which was applied in the area in the 1980's (Kuneš et al. 2007b).

The increased foliar S concentrations indicate persisting S load in the mountain environment of the northern part of the Czech Republic in the period after massive air pollution disaster.

In general, P and K seem to be the most limited macroelements in the nutrition of speckled alder plantation on the site. A small difference in P and K concentrations between the control and fertilized treatments might result from the low content and small solubility of the elements in the applied amendment. Similarly like in the other speckled alder plantation on the site (Kuneš et al. 2009), P and K released from the amendment in the fertilized treatments might have been diluted in a higher volume of biomass of faster growing trees. Re-fertilization with slow-release synthetic PK fertilizer is thus recommendable.

Although the amendment itself consisting of crushed basic rocks is cheap, there is no doubt about the high labour consumption and costs of application of this heavy material (Kuneš et al. 2009). It should nonetheless be emphasized that such measures are not to be taken on large areas but on the most degraded small patches where replanting failed several times.

At present, synthetic slow-release fertilizers in combination with bio-ameliorating pioneer broadleaves are tested to address the cumbersome application of basic rocks. The outcomes of our experiment documented that the application of slow-acting rock powders can significantly promote the growth and survival of alder on a degraded site and thus contribute to its stabilization.

CONCLUSIONS

Man-planted speckled alder was able to survive and grow satisfactorily under harsh conditions in the Jizerské hory Mts. even above the altitudinal zone of its common occurrence. No post-planting shock (typical of target trees such as beech, fir and also Norway spruce) was recorded. Therefore speckled alder seems to be a promising species for establishing the pioneer stands on degraded mountain sites.

The plantation positively responded to the application of slow-release basic amendment. The growth of alders was significantly promoted in terms of height, basal stem diameter and width of crown. A positive effect on survival was also evident, though it was significant in the PLH treatment only. The effects of fertilization with a mixture of basic rocks were recorded in Ca and Mg concentrations in the initial years after planting. The concentrations of P and K, the most limited macroelements in alder nutrition on the site, were not markedly influenced. In general the slow-acting powders of basic rocks could be an effective fertilizer for alders, however, they are applicable only on the most degraded small patches of air polluted sites. The placement of the slow-release amendment in planting holes seems to be more efficient mainly in terms of survival promotion. Nonetheless, the surface application in small circles around trees was less laborious and yielded also satisfactory results.

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