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Influence of pulverized limestone and amphibolite mixture on the growth performance of *Alnus incana* (L.) Moench plantation on an acidified mountain site

I. Kuneš[1], **V. Balcar**[3], **T. Benešová**[1], **M. Baláš**[1], **J. Zadina**[1], **D. Zahradník**[1], **J. Vítámvás**[1], **D. Kacálek**[3], **O. Špulák**[3], **M. Jakl**[2], **J. Jaklová Dytrtová**[2], **V. Podrázský**[1]

[1]*Faculty of Forestry and Wood Sciences, Czech University of Life Sciences in Prague, Prague, Czech Republic*
[2]*Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Sciences in Prague, Prague, Czech Republic*
[3]*Forestry and Game Management Research Institute, Strnady, Opočno Research Station, Opočno, Czech Republic*

ABSTRACT: A young speckled alder (*Alnus incana* [L.] Moench) stand was planted on a tract clear-felled due to air pollution and located on a summit plateau of the Jizerské hory Mts. (Central Europe, Czech Republic) at an altitude of 950 m a.s.l. The aim of the experiment was to test the suitability of *Alnus incana* to form preparatory stands covering the site and thus enabling the reintroduction of more sensitive target species. A potential of *Alnus incana* to respond to slow-release fertilizing was tested as well. The control treatment showed sufficient growth dynamics, nevertheless, the fertilization significantly promoted the growth (documented by height, height increment and stem-base diameter). If some limitations of alder such as high light requirements are respected, the speckled alder can be recommended as a suitable species for preparatory stands even in the 7th and 8th altitudinal (vegetation) zones, especially when fertilized.

Keywords: Jizerské hory Mts.; chemical amelioration; biological amelioration; initial fertilizing; pioneer species; height increment; mortality; crown diameter; stem-base diameter

Norway spruce (*Picea abies* [L.] Karst.) is naturally a principal tree species in the upper and summit parts of the Jizerské hory Mts., nonetheless, a broadleaved admixture, such as European beech (*Fagus sylvatica* L.), rowan (*Sorbus aucuparia* L.), birch (*Betula* sp.), sycamore maple (*Acer pseudoplatanus* L.) etc., was typical of the local indigenous forests. The broadleaved admixture has been reduced due to human activities in the course of history.

Moreover, during the air-pollution disaster in the 1970s and 1980s, the allochthonous conifers were often cultivated in the most affected mountain parts (Pěnička 2007) for their better pollution resistance. Blue spruce (*Picea pungens* Engelmann) is the most important representative. At present, when the disaster is over and the air-pollution input to the forest ecosystems is lowered, these allochthonous stands should successively be converted into stands composed of more convenient native tree species (Balcar, Kacálek 2008a).

The young coniferous plantations, which have replaced the old forests disturbed by pollution, are

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still rather gappy (non-existent) at some places (usually on most extreme sites), with empty patches after failed plantations. As an exception, it is possible to accept this gappy character of stands in order to increase their structural diversity. However, it is not desirable to conceive this approach as commonly applicable because of a risk of soil organic matter losses through mineralization and the necessity of sufficient tree litter input to soil (Ussiry, Johnson 2007). On stony and skeletal soils and soils covering boulder substrata, a rapid replanting of empty patches is essential in order to prevent introskeletal soil erosion (Šach 1990; Vacek et al. 2003).

On the one hand, the requirement to convert the allochthonous blue spruce stands as well as the need to refill the gaps after failed plantations is a difficult task in a harsh mountainous environment, on the other hand it is an opportunity to introduce a broadleaved admixture there and thus to diversify the coniferous stands in terms of composition and structure.

Some more sensitive target broadleaves such as European beech (*Fagus sylvatica* L.) and sycamore maple (*Acer pseudoplatanus* L.) need a canopy cover for reintroduction on the environmentally harsh sites. Speckled alder might be a suitable species to form preparatory stands in order to ensure the ecological cover that is required by more sensitive trees.

The objectives of this contribution are as follows: (1) to validate that speckled alder (*Alnus incana* Moench) is a convenient species for introduction to the gaps left after failed plantations or made during the conversion of blue spruce stands even under environmentally highly stressing conditions, (2) to assess the foliar nutrient status of the alder as a precondition of positive influence on forest soil, (3) to verify the influence of localized application of basic amendments on the growth performance of speckled alder.

MATERIAL AND METHODS

The planting experiment was installed in the Jizerské hory Mts. as a part of the Jizerka Field Experiment (Balcar, Podrázský 1994) on a formerly clear-felled tract on the Central Ridge of the Jizerské hory Mts. (latitude 50°49'34"N, longitude 15°21'19"E, Northern Bohemia). The experimental plantation is located on the south-facing slope of the ridge at an altitude of 950 m. The mean annual air temperature (1996–2007) at the site is 5.1°C and the mean annual precipitation (1994–2007) is 1,093 mm (Balcar, Kacálek 2008b). The bedrock was determined as biotitic granite, the soil as mountain humus Podzol. The herbaceous vegetation is dominated by *Calamagrostis villosa* (Chaix) J. F. Gmelin. The experimental plot is game-proof fenced.

The experimental plantation was established in spring 2000. Altogether 142 seedlings (one-year-old bare-rooted planting stock) originating from the Jizerské hory mountains, 6th forest altitudinal (vegetation) zone, were planted in three subplots (replications). In spring 2002, half of the living trees in each replication were treated with a mixture of amphibolite and limestone. In the fertilized variant, 1 kg of this mixture was applied per each tree as a base dressing in a circle around the stem so that the circle of the soil sprinkled with this mixture was approximately 0.5 m in diameter.

The proportion of limestone and amphibolite in the mixture was equal. The crushed dolomitic limestone (56.7% of $CaCO_3$ and 39.4% of $MgCO_3$) contained 93.5% of particles smaller than 1 mm in diameter and the pulverized amphibolite (11.11% of CaO, 7.31% of MgO, 0.18% of P_2O_5, 0.23% of K_2O) contained 45.5% of particles smaller than 0.06 mm, 46.6% of particles between 0.06 and 0.1mm, 6.3% of particles between 0.1 and 0.6 mm and 1.6% of particles larger than 0.6 mm in diameter.

Tree heights were measured to the nearest 1 cm and crown diameter to the nearest 10 cm. A calliper was used to measure the stem base diameter to the nearest 1 mm. The 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, i.e. it can 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.

The nutrition analyses are presented in percentages of macroelements (N, P, K, Ca, Mg, S) in dry matter of assimilatory (leaf) tissues. A composite sample of leaves from each variant was taken in the period from mid-August to the beginning of September, when the aboveground parts of the trees had finished their active growth. The healthy fully developed leaves were pooled in the samples that were analyzed at the Tomáš Laboratory using the procedures described by Zbíral (1994).

Height increment, stem-base diameter and crown diameter were statistically analyzed using the Mann-Whitney *U* tests. The Statistica 8.0 software was used for this statistical procedure, which is in detail described by Hill and Lewicki (2006).

Table 1. Development of total mortality rate (%)

Variant	00	01	02s	02a	03	04	05	06	07	08
Control	21.1	33.1	38.0	42.0	44.7	44.7	44.7	44.7	44.7	44.7
Fertilized	21.1	33.1	38.0	40.9	40.9	42.4	42.4	42.4	42.4	42.4

Table 2. Development of annual height increment values (i) (cm) and periodic annual height increment (I 2002–2008); the i01a/i02s column expresses a decrease in height during the winter period before the amendment application

Year		i00	i01	i01a/02s	i02	i03	i04	i05	i06	i07	i08	I 02-08
Significance						x	x				x	xx
Control	m (cm)	14.70	26.90	–6.90	44.60	29.70	21.50	23.00	4.00	16.60	46.30	26.50
	sd (cm)	10.31	14.59	13.37	20.39	12.62	18.34	18.67	20.42	15.42	22.68	8.83
Fertilized	m (cm)	14.20	22.90	–8.90	51.70	36.70	29.10	29.80	–0.90	21.80	55.90	32.00
	sd (cm)	8.48	14.22	13.92	19.05	12.88	9.88	9.76	31.31	14.08	18.91	8.13

m – mean, sd – standard deviation, x and xx – marks stand for $p < 0.05$ and $p < 0.01$, respectively

Trends in the nutrition of plantations were evaluated using the linear-regression lines smoothing the macroelement concentrations recorded within a variant in the years of sampling. For each macroelement and variant, the existence of a significant divergence of the time axis and regression line representing the development in a macroelement concentration was examined. For each macroelement, mutual parallelism of regression lines representing the compared variants was also tested. The methods are described by ANDĚL (1998) and were executed by S-Plus 6.1 software. The confidence level of 95% was chosen in all statistical tests.

RESULTS

The most significant increase in the total mortality rate by 38% occurred before the amendment was applied (Table 1). From spring 2002 to autumn 2008, the total mortality rate rose only by 6.7% and 4.4% in the control and fertilized variant, respectively. The total mortality rate in 2008 did not significantly differ between the compared variants.

The fertilized variant was slightly disadvantaged in mean height as compared to the control in spring 2002, when the amendment was applied (Fig. 1, Table 2). During the vegetation period 2002 this head start of the control dissipated and since 2003 the fertilized variant was gaining advantage over the control. The difference in mean height between the compared variants became significant in 2007 (*p*-level = 0.044) and 2008 (*p*-level = 0.025), respectively.

The stimulating effect of the applied amendment is apparent (Table 2). After the application of the mixture in spring 2002, the height increment values

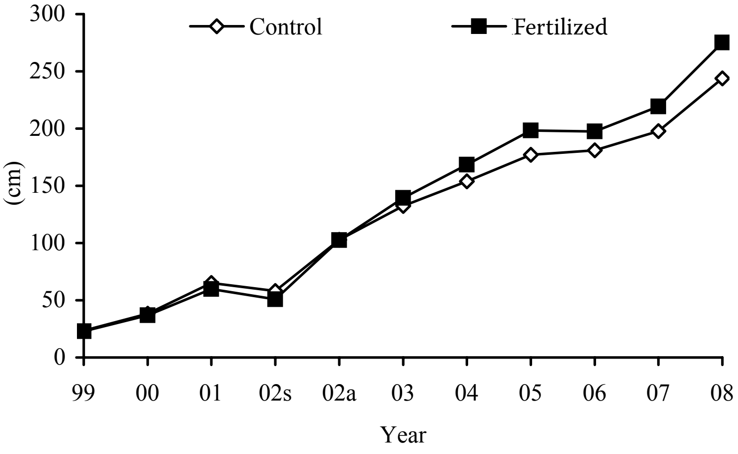

Fig. 1. Development of mean height; the 02s and 02a records on the time axis stand for the spring and autumn of 2002, respectively

Table 3. Stem-base diameter (cm)

Year		03	04	05	06	07	08
Significance					x	x	xx
Control	m (cm)	1.60	2.00	2.80	2.90	3.50	4.10
	sd (cm)	0.61	0.74	0.98	1.03	1.22	1.36
Fertilized	m (cm)	1.70	2.30	3.10	3.40	4.10	4.80
	sd (cm)	0.55	0.71	0.93	0.94	1.16	1.35

m – mean, sd – standard deviation, x and xx – marks stand for $p < 0.05$ and $p < 0.01$, respectively

Table 4. Development of crown diameter values (cm)

Year		03	04	05	06	07	08
Significance			x				
Control	m (cm)	72.0	88.0	111.0	113.0	133.0	158.0
	sd (cm)	30.2	34.5	40.9	41.3	39.6	47.9
Fertilized	m (cm)	76.0	103.0	125.0	127.0	149.0	174.0
	sd (cm)	24.5	28.8	33.8	31.7	30.1	43.4

m – mean, sd – standard deviation, x – mark stands for $p < 0.05$

in the fertilized variant were always higher than in the control (with the exception of 2006), although the difference was significant in 2003, 2004 and 2008 only. The cumulative effect of the higher annual increment values in the fertilized variant during the period since 2002 finds its expression in the mean values of periodic annual increment, which is by more than 20% higher in the fertilized variant than in the control (100%).

As for 2006, the low value of the annual height increment in the control and its negative value in the fertilized variant are consequences of mechanical damage caused by snow (see Discussion).

The effect of amendment application on the stem-base diameter of young alder trees was significant since 2006 (Table 3). Although the means of crown diameter (Table 4) in the fertilized variant seem higher than in control, it was only in 2004 when this

Table 5. Dry mass concentrations of macroelements in alder foliage and dry weight of 100 leaves

Year	Variant	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	m 100 leaves (g)
2002	control	2.98	0.15	0.53	0.70	0.330	0.19	17.55
	fertilized	2.86	0.15	0.46	0.70	0.365	0.18	20.33
2003	control	2.42	0.16	0.39	0.67	0.395	0.18	19.14
	fertilized	2.43	0.17	0.40	0.69	0.450	0.18	20.54
2004	control	3.12	0.14	0.53	0.57	0.370	0.16	
	fertilized	3.19	0.15	0.56	0.54	0.380	0.15	
2007	control	2.76	0.26	0.78	0.57	0.289	0.16	24.89
	fertilized	2.76	0.27	0.77	0.51	0.268	0.18	23.62
2008	control	2.81	0.35	0.55	0.46	0.259	0.17	18.95
	fertilized	3.05	0.34	0.58	0.49	0.287	0.15	19.20

difference was significant due to a variation in the crown diameter values.

The nutritional status (Table 5) was assessed on the basis of foliar macroelement concentration. According to provisional criteria for the assessment of foliar content published by Kopinga and Van den Burg (1995), the concentration of N ranges between the normal and the optimal level irrespectively of the variant. The concentration of P gradually rose from a low to optimal level in both variants. The K concentration was low with the exception of 2007, when it reached a normal level in both variants. As for Ca content, no criteria for assessment are available, however, we can assume that Ca content, despite a decreasing trend, still remains sufficient. The Mg concentration is still on an optimal level in both variants. Nevertheless, there are indications of a decreasing trend, although, contrary to Ca, they are not significant. The foliar S concentration is slightly increased.

For the reference period, a significantly upward trend in the foliar P concentration was found in the control (p-level = 0.023) as well as in the fertilized variant (p-level = 0.015). On the contrary, the foliar Ca concentration in both variants showed a significantly downward trend with p-levels of 0.032 and 0.037 for the control and fertilized variant, respectively. No further significant (upward or downward) trends in the nutritional status were recognized. No significant divergence of regression lines smoothing the concentration values in the compared variants was found.

An upward trend in the P:N ratio values was found as significant in both variants (Table 6). Despite some fluctuations, the K/Ca ratio was classified as significantly rising in the control variant, a similar trend in the fertilized variant remained below the level of significance. The K/Ca ratio indicates a possible deficiency of K in relation to Ca according to the classification by Kopinga and Van den Burg (1995) in both variants during the period from 2002 to 2004.

DISCUSSION

The initial plantation losses in the course of 2000 were probably caused chiefly by soil drought as a consequence of the unusually warm and dry weather in spring 2000; see the climatic data in Balcar and Kacálek (2008b). The rise in mortality rate during the period of 2001 and 2002 is in line with expectations. The trees bent by snow or partially broken afterwards usually succumbed to damage or to the weed competition of *Calamagrostis villosa,* which is vigorous on the site. Saarsalmi in Uri et al. (2002) also reported that small seedlings of grey alder suffered from weed competition. The mortality rate in the course of the period from 2003 to 2008 was substantially lower than in the initial years.

Since the amendment was applied two years after planting, it could not influence the total mortality rate significantly. Nonetheless, if the amendment is applied at the time of planting, the fertilizing stimulus is able to increase the survival rate (Kuneš et al. 2008).

As for the height growth of plantation, the i01a/02s value should be explained, which expresses a decrease in height during the winter period through

Table 6. Proportion values of nutrition elements to N (=100%) in dry mass of leaves (the 1st section of the table) and basic cation ratios in the leaves (the 2nd section of the table)

Variant	Year	N	K	P	Ca	Mg	K:Ca	K:Mg
Control	2002	100	18	5	23	11	0.76	1.6
	2003	100	16	6	28	16	0.58	1.0
	2004	100	17	4	18	12	0.93	1.4
	2007	100	28	9	21	10	1.37	2.7
	2008	100	20	13	16	9	1.20	2.1
Fertilized	2002	100	16	5	25	13	0.66	1.3
	2003	100	16	7	28	18	0.58	0.9
	2004	100	18	5	17	12	1.04	1.5
	2007	100	28	10	18	10	1.51	2.9
	2008	100	19	11	16	9	1.18	2.0

snow and rime. The height in spring 2001 was extraordinarily distinguished, because the amendment was applied at that time. It can be expected that in such a climatically exposed site this decrease occurs almost annually and is usually compensated by tree height increment during the subsequent vegetation period.

The increment in 2006 is an exception. The 2005/2006 winter was exceptionally rich in snow. The snow cover reached more than 2 m on the site that year and the snow inflicted serious mechanical damage to forest stands of many species on the site. The alder plantation was affected by frequent breakages (negative changes in height values) that were not fully counterbalanced by shoot elongation in the next vegetation period.

Based on the growth dynamics after planting, speckled alder can be classified as a suitable preparatory species even under the harsh environmental conditions of the 7th and 8th forest altitudinal zones. No growth stagnation as a result of transplanting shock was observed in the initial years after planting. It is, however, important to respect its high light-requirements and wood fragility. The expected lifespan of preparatory stands with an increased proportion of speckled alder is not long under harsh climatic conditions of the 8th altitudinal zone: let us assume 15–20 years. During this time, however, speckled alder is able to provide an environmental shelter for more sensitive species, such as beech (*Fagus sylvatica* L.) and sycamore maple (*Acer pseudoplatanus* L.) planted under the cover of its canopy.

Speckled alder also supplies the site with a large amount of valuable litter. Uri et al. (2002) reported that a young speckled alder stand planted at high density (1 × 0.7 m) on an abandoned agricultural land was able to produce 1.97 t of dry mass per hectare four years after planting. A potential risk of elevated N leaching from the ecosystem as a result of the N-rich litter input can partially be counteracted by P fertilization (Gökkaya et al. 2006).

As follows from the comparison with literature sources compiled and quoted by Uri et al. (2002), the N status of alder trees in our experiment (assessed on the basis of foliar analyses) is within the range of concentrations recorded also elsewhere in Europe. This is probably a result of the N_2 fixation ability of alder. This ability is high; Ingestad (1980) stated that the N_2 fixation alone, without addition of mineral nitrogen, resulted in an almost optimum nitrogen status. Near-complete reliance of alder on N_2 fixation was also mentioned by Chambers et al. (2004). In more concrete terms, according to Myrold and Huss-Danell (2003) the percentage of N derived from the atmosphere ranges between 70% and almost 100%. Similarly Hurd et al. (2001) reported that speckled alder (*Alnus incana* ssp. *rugosa*) was able to derive 85–100% of its foliar N from N_2 fixation.

Kopinga and Van den Burg (1995) presented a general estimate of the optimal ratio of foliar nutrient concentrations related to N for broadleaves as follows: 100N:50–100K:10–14P:10Mg. They concluded that even at sufficient levels of P, K, and Mg there might be a relative deficiency when the N concentration was too high.

The P demand of alder is higher than that of other (N_2-non-fixing) broadleaves. According to Ingestad (1981), the nutrient ratios required by speckled alder are 100N:50 K:18P, while those of silver birch (*Betula verrucosa* Ehrh.) are 100N:65K:13P. Similarly Hytönen et al. (1996) reported that more phosphorus per unit biomass was bound in grey alder compared to downy birch (*Betula pubescens* Ehrh.).

In our experiment, the concentration of foliar P rose from low to optimal values. This rise in foliar P concentrations (Table 5) occurred in both variants, which might indicate that the mycorrhizal symbiosis played an important role in the P acquisition on the site. Monzón and Azcón (2001) found out that arbuscular mycorrhiza was more important for optimum P acquisition and growth of speckled alder than P fertilizing (without mycorrhizal inoculation).

Although the foliar P concentration is on an adequate level in our plantation, if we take into account the required ratios for optimal nutrition presented by Ingestad (1981), the foliar P content still seems somewhat low in relation to the foliar N content (lower than 18:100). A lower foliar P:N ratio in dry mass of foliage was observed also by Uri et al. (2003). This discrepancy might be related to the allocation of received P to particular tree compartments.

K seems to be the most deprived macroelement in the nutrient supply of our plantation. When the classification by Kopinga and Van den Burg (1995) is used, the concentrations of K fluctuate closely above the border line between low and deficient supply and are markedly lower than 12 g/kg reported by Uri et al. (2003) in a young alder plantation on an abandoned (supposedly nutritive) agricultural land. In the period between 2002 and 2004, the limitation in K supply is indicated also by the K/Ca ratio whose normal values range between 1 and 3.5 according to Kopinga and Van den Burg (1995). The fact that the K/Ca ratio finally got into the normal range is rather a result of a consistently decreasing concentration of Ca than of an improvement in the K nutritional status.

The situation regarding Mg and Ca is rather complex. Immediately after the application of the amendment mixture, when there must have been an abundant Ca and Mg supply in the fertilized treatment, only marginal differences in the foliar concentrations of Ca and Mg were detectable between the variants. The decreasing Mg and Ca trends are common for both variants and their concentration curves follow the same pattern.

If there were a higher demand for Ca and Mg than that reflected through the decreasing foliar concentrations, it is highly probable that the supply potential in the fertilized variant would be high enough to meet it. This assumption is based on the high dosage, slow-release character of the ameliorative mixture and on the way of its application. Therefore, if the laboratory results are relevant, the Ca and Mg decrease may reflect rather a certain physiological reason than the sneaking Ca and Mg depletion.

An increased concentration of foliar S indicates the saturation of the ecosystem with this noxious element, which is a result of the extreme SO_2-load in the 20th century and, to some extent, it also documents the persisting S deposition.

In general, the amendment application resulted in significant growth stimulation, however, without any marked reflection in the foliar composition. In all probability, the basic mixture altered the soil environment in the rhizosphere of alders (increased pH and saturated soil with basic cations, mainly Ca). Improved soil chemistry probably stimulated roots, N uptake and thus promoted the growth of trees. Although the role of pH on the mycorrhiza is not fully clarified, the available Ca and base saturation are most probably beneficial (Crannell et al. 1994). Nonetheless, the supposedly improved nutrient uptake in the fertilized variant might have been diluted in a higher volume of biomass of faster growing trees.

A detailed analysis of biomass composition and determination of nutrient allocation to the particular tree compartments as well as to layers in the soil profile might help to answer some questions implied in the discussion and confirm or confute the hypotheses formulated above.

CONCLUSIONS

Speckled alder has a good growth potential even in at the highest mountain elevations. Whatever mechanisms play a decisive role in growth stimulation after the application of basic amendments, speckled alder is able to respond significantly to amelioration even in a climatically harsh environment, where the positive reaction of many target tree species is scanty, if any. Alder is able to fix N_2 and supply the soil with biomass of N-rich litter. The fertilization should be applied at the time of planting.

If some limitations of alder such as high light requirement and wood fragility are respected, speckled alder can be recommended as a valuable species for preparatory stands, e.g. together with Carpathian birch (*Betula carpatica* W. et K.) and rowan (*Sorbus aucuparia* L.) even in the 7th and 8th altitudinal (vegetation) zones.

This recommendation is valid from the standpoint of silviculture; there are unfortunately some obstacles in the latest Czech legislation that confines a more abundant use of speckled alder at the highest elevations. This species e.g. cannot cover more than 15% of reduced forest area in the 7th and 8th forest altitudinal zones, which limits its share in the composition of preparatory stands.

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Vliv směsi mletého dolomitu a amfibolitu na prosperitu kultury *Alnus incana* (L.) Moench na acidifikovaném horském stanovišti

ABSTRAKT: Na imisní holině vrcholového plata Jizerských hor v nadmořské výšce 950 m byla založena pokusná kultura olše šedé (*Alnus incana* [L.] Moench). Cílem pokusné výsadby bylo posoudit použitelnost olše šedé pro tvorbu přípravných porostů, které vytvoří ekologický kryt nezbytný pro vnesení citlivějších cílových druhů. Byl testován rovněž potenciál olše šedé zareagovat na cílené přihnojení v daných podmínkách. Kontrolní výsadba bez přihnojení vykazovala uspokojivou růstovou dynamiku, ale přihnojení směsí dolomitického vápence a amfibolitu mělo pozitivní vliv na urychlení růstu (průkazně doložitelný na průměrné výšce, výškovém přírůstu i tloušťce kmínku). Lze konstatovat, že pokud budou respektovány ekologické požadavky olše šedé, jako jsou vysoké nároky na světlo, olše může být doporučena jako vhodný druh pro tvorbu přípravných porostů i v 7. a 8. lesním vegetačním stupni, obzvláště po cíleném přihnojení.

Klíčová slova: Jizerské hory; chemická meliorace; biologická meliorace; iniciační přihnojení; pionýrské druhy; růst; mortalita; šířka koruny; tloušťka kmínku

Corresponding author:

Ing. Ivan Kuneš, Ph.D., Česká zemědělská univerzita v Praze, Fakulta lesnická a dřevařská, 165 21 Praha 6-Suchdol, Česká republika
tel.: + 420 224 383 792, fax: + 420 234 381 822, e-mail: kunes@fld.czu.cz