Prosperity of spruce plantation after application of dolomitic limestone powder

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ABSTRACT: The subject of this paper was to assess the effects of pulverised dolomitic limestone applications on prosperity of Norway spruce (*Picea abies* L.) plantation and on the soil in extreme ecological conditions of the Jizerské hory Mts. The characteristics such as plant mortality, annual height increment, diameter of root collar (stem base diameter), crown diameter, nutrient analyses and some data from soil analyses are evaluated in this paper. An eleven-year period of observations is summarised. According to the observations and measurements carried out until now, the effect of limestone applications (1 kg per tree) on the spruce plantation prosperity seems to be positive without any serious negative impacts on the soil.

Keywords: Norway spruce; Jizerské hory Mts.; liming; forest soils; soil properties; chemical amelioration

The Jizerské hory Mts. are border mountains in northern Bohemia. A vast forest decline occurred in the highest elevations of the Jizerské hory Mts. during the second part of the 1970s and in the 1980s. High concentrations of air pollutants and deposition of pollutants in the soil were the main causes of this serious phenomenon. We consider SO_x that was generated on a massive scale by German and Polish power stations at that time as one of the most harmful substances. These power stations are located in the basin at the foothills of the pollution-damaged mountain range. They burnt, and in some cases they still burn, brown coal of low quality with a high content of sulphur and fluorine, which could be another noxious substance for the forest ecosystems there.

The power plants in this area emitted enormous quantities of pollutants not long ago. For instance: 900,000 tons of SO_x per year were emitted in 1990 (BALCAR, PODRÁZSKÝ 1994). Later in the 1990s a substantial improvement occurred as a consequence of a decrease in electric power production and the installation of desulphurisation technologies. Nonetheless, the situation is still very complicated. There arose vast clear-cut areas in the Jizerské hory Mts. as a result of air pollution. The total area of these clearings stabilised in 1995. It amounted to 12,000 ha (BALCAR 1998). Finally, a larger portion of the clear-cut areas has been reforested. Nevertheless, it was achieved at the cost of heavy losses. The plants set out at these sites miss the ecological protection of older stands and are under strong environmental stress (climate, remaining pollution impact and game damage). Furthermore, the young stands are not fully ecologically functional.

Hoofed game stocks that are above the contemporary environmental capacity of the affected ecosystem pose a big problem in the Jizerské hory Mts. (PODRÁZSKÝ 1995). A reduction in the game population densities is a hard and long-term task because of migration. But it is necessary. The game cause damage to new plant and almost eliminate natural seeding. As a consequence, very stable grass coenosis that has a "pseudoclimax" character is developed. Although these grass communities protect the soil against direct wind and water erosion, they are not able to prevent losses of organic matters from the soil (excessive humus mineralisation) because the grass coenosis cannot fix so many organic matters in its biomass and necromass as a functional forest ecosystem can. Without successful reforestation of clear-cut areas by prosperous forest ecosystems in the near future a high amount of nitrogen fixed in organic components of soil could be lost instead of being transformed and deposited into the biomass of new forests. The organic carbon balance could also be heavily affected. The point is that the mineralisation of organic carbon, which is accelerated by deforestation of the site, is not compensated by a sufficient input of organic litter produced by a vigorous stand. Therefore the prompt restoration of functional and stable forest ecosystems is of crucial importance.

This experiment was conducted in co-operation of Forestry and Game Management Research Institute – Opočno Research Station and Forestry Faculty of Czech University of Agriculture in Prague. It was funded under Research Project MSM 414100009 *Restoration of Functioning Forest Ecosystems of the Krušné hory Mts.*

MATERIAL AND METHODS

A planting experiment was established in the Central Ridge of the Jizerské hory Mts. at an altitude of about 960 m a.s.l. in 1990. The mean annual air temperature fluctuates between 4 and 5°C and the mean annual precipitation is approximately 1,470 mm in this area (BALCAR, PODRÁZSKÝ 1994, 1995). The bedrock is biotitic granite, the soil type is determined as mountain humus podzol (Ferro-humic Podzol according to the FAO terminology). One of the aims of the experiment is to test the influence of chemical amelioration on soil properties and on the prosperity of tree species that are potentially suitable for the restoration of forest ecosystems under air pollution stress. A spruce plantation described in this paper is a part of the experiment.

The experimental plantation consists of 10 subplots (10 × 10 m) of Norway spruce (*Picea abies* L.). It was planted in the spring of 1991. Each subplot contained 50 trees at the spacing of 1 × 2 m at that time. The planting stock was 4 years old in 1991. The young spruce plants originated from the Děčínsko area (northern Bohemia).

In addition to control variant (4 subplots), two alternative limed variants were established:

– Surface application (3 subplots), i.e. 1 kg of dolomitic limestone powder was applied onto the soil surface around each tree, so that the limed area formed circles around all trees of this variant. The circles were roughly 1 m in diameter.
– Planting pit application (3 subplots), i.e. 1 kg of dolomitic limestone powder was mixed with soil in the space of planting pits during planting.

Dolomitic limestone from the pit Horní Lánov was used. Chemical and structural properties of limestone powder:

The content of Ca was 21.5% and of Mg 11.3%. The amelioration material consisted of 5.8% of particles with the diameter over 1 mm, 16.3% of particles with the diameter between 1.0 and 0.5 (mm), 20.4% of particles with the diameter between 0.5 and 0.2 (mm) and 57.2% of particles whose diameter was below 0.2 mm.

The paper summarises the outputs of measurements that were made in an eleven-year period of observations (1991–2001) including mortality, annual height increment, diameter of root collar (stem base diameter), crown diameter, macronutrient analyses of assimilatory tissues and soil chemistry. The mortality and annual increment were established annually, the other characteristics usually at longer intervals.

A scaled rod is used to measure tree height values and to determine crown diameters. Tree height values are measured to the nearest ±1 cm and those of crown diameters to the nearest ±10 cm. A calliper is used to measure stem base diameters; the accuracy of these measurements is ±1 mm.

Except for mortality, the results of the other above-mentioned biometrical characteristics were statistically analysed using ANOVA, Homogeneity of Variance Test – Bartlett's Procedure and Multiple Comparisons. The chosen confidence level was 95%. The statistically processed files consist of the data that belong only to the trees surviving in 2001.

A form of presentation of statistical results: different letter indexes at the values compared in pairs indicate statistical differences. The values of Bartlett's test are in percentages: lower value than 5% could mean a further partial decrease in the confidence of statistical conclusion below 95%.

In addition to the above-mentioned characteristics of trees, tree nutrition analyses were carried out and soil properties were also determined (no detailed statistical analysis).

Samples of assimilatory tissues for nutrition analyses were taken in the off-season period (usually in the second half of October) in 1994, 1996, 1999, 2000 and 2001. A composite sample was formed for each variant and consisted of the newest needle generation. The sampled needles originated from annual shoots in the third whorl. The nutrition analysis of assimilatory tissues is presented in percentages of macroelements (N, P, K, Ca, Mg, S) in dry matter of assimilatory tissues.

The outputs of soil analyses presented in this paper originate from composite soil samples that were taken by a soil corer directly from the space of planting pits in the autumn seasons of 1993 and 1998. They originate from the surface soil layer (a mixture of an ectogranic and partially an endogranic humus horizon in the planting pit), the depth of which is 20 cm.

The following chemical properties of fine earth were determined: pH in water and 1 N KCl, soil adsorption complex characteristics according to Kappen (S – base content, H – hydrolytical acidity, T – cation exchange capacity, V – base saturation), total carbon and nitrogen (Kjeldahl) contents and plant available nutrients in 1% citric acid solution. In this case, plant available P was determined by the Spekol 210 apparatus, plant available K by flame photometry, plant available Ca and Mg by AAS.

The samples of assimilatory tissues and soil samples were analysed in the laboratory Tomáš (FGMRI – Research Station Opočno) by standardised procedures (ZBÍRAL 1994, 1995, 1996).

The limits of nutrient deficiency are based on commonly used data (DE VRIES 1998) that were modified as a matter of experience acquired on the experimental plot.

RESULTS

Plantation development

Mortality (Fig. 1)

Regardless of the variants, the young plantations of spruce showed the highest rate of annual mortality (A.M.) in the first four years after planting on the experimental plot. This could be ascribed to a "planting shock". Young trees from a nursery are not usually fully adapted to such

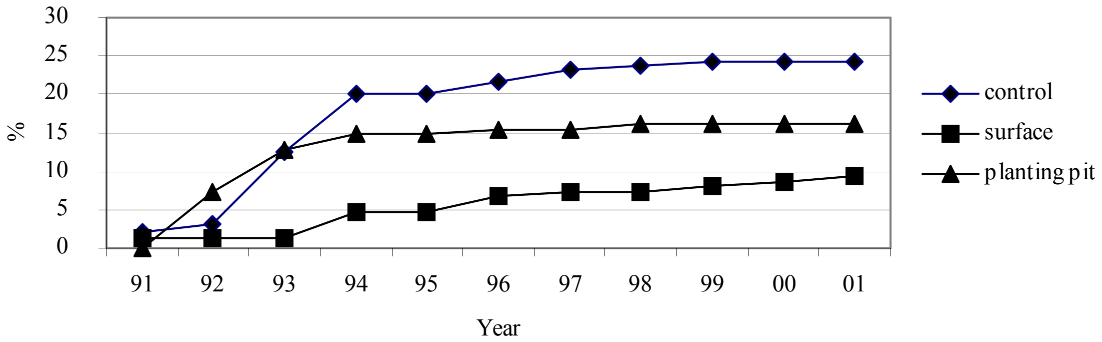


Fig. 1. Development of total mortality of particular variants

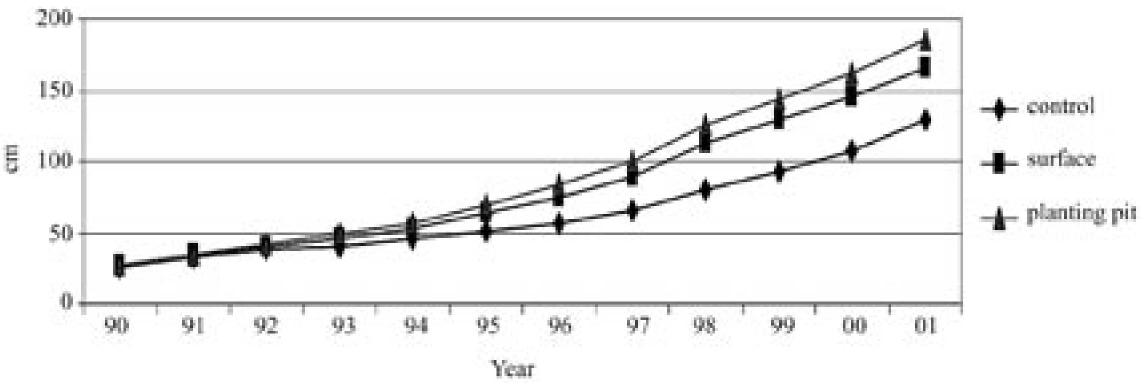


Fig. 2. Development of average plantation height

a poor and extreme site – a higher rate of annual mortality is peculiar to the process of adaptation. The plantations of all three experimental variants stabilised by 1995 – the annual mortality rate has not exceeded 2% since that time. In 2001, the total mortality rate (T.M.) indicated a positive effect of applied limestone powder on the prosperity of young spruce plantations:

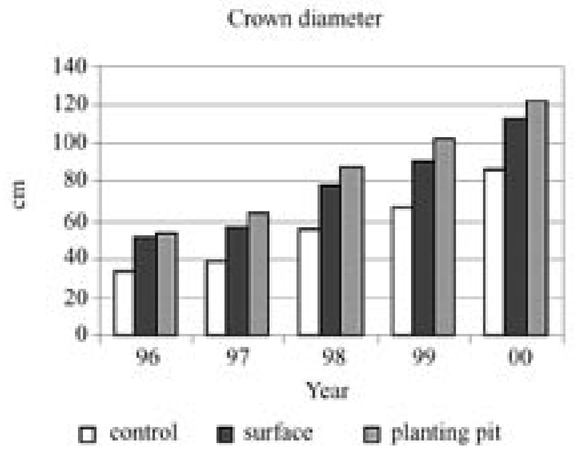
T.M.$_{\text{CONTROL}}$ = 24%; T.M.$_{\text{PLANTING PIT}}$ = 16%;
T.M.$_{\text{SURFACE}}$ = 9%.

Height growth and mean height (Fig. 2, Table 1)

The "planting shock" is detectable in a slight drop of the annual increment rate of all variants. The current annual increment (C.A.I.) of the limed plantations ("surface" and "planting pit") ceased to decrease after 1992 and that of the control plantation stabilised a year later. The plantations of all three variants grew at an accelerating pace from 1993 to 1998. Nevertheless, the current annual increment values of the limed variants were significantly higher than those of the "control" variant. After an increment culmination (1998) an obvious decrease in the C.A.I. values of limed variants was observed in the period from 1999 to 2000. By contrast, the C.A.I. drop of "control" variant was very slight and had a form of stagnation in the C.A.I. development curve. Current C.A.I. values (2001) document revitalisation of the growth rate of all variants. The differences in the C.A.I. values between the control variant

Table 1. Development of annual height increment

		Annual height increment											
Year		ih91	ih92	ih93	ih94	ih95	ih96	ih97	ih98	ih99	ih00	ih01	ih91–01
Bartlett's test (%)		23	0	0	4	0	0	0	73	2	0	2	5
Control	*x* (cm)	8.1a	4.1a	3.1a	5.0a	5.6a	6.2a	8.9a	13.8a	13.1a	13.7a	21.7a	9.4a
	s (cm)	5.00	2.76	2.53	3.52	5.97	5.54	7.89	10.09	8.26	10.79	12.70	4.37
Surface	*x* (cm)	8.3a	5.2b	5.3b	7.7b	9.9b	10.9b	14.7b	23.5b	17.6b	15.1a	20.8a	12.6b
	s (cm)	4.35	3.60	3.48	3.77	10.52	8.07	10.19	10.72	9.70	10.10	11.66	4.20
Planting pit	*x* (cm)	7.9a	6.8c	7.4c	8.5b	11.6b	14.5c	16.3b	26.5b	18.6b	17.0a	23.4a	14.4c
	s (cm)	4.53	3.83	4.67	4.36	8.01	9.61	10.96	10.65	10.46	14.35	14.84	5.14



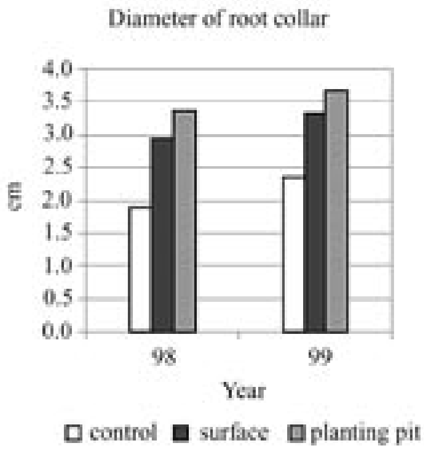


Fig. 3. Development of crown diameter and stem base diameter

and the limed ones seem to have diminished during the period from 1998 to 2001. It could also indicate a reduction in the effects of experimental liming. However, the overall stimulating effect of liming on the height growth of spruce plantations is obvious in the past period of observation (1991–2001). The periodic annual increment P.A.I. (91–01) can be used for demonstration:

$P.A.I._{SURFACE} = 134\%\ P.A.I._{CONTROL}$

$P.A.I._{PLANTING\ PIT} = 158\%\ P.A.I._{CONTROL}$

The mean height of "control" variant increased five times, that of "surface" variant six times, and that of "planting pit" variant increased seven times during the period from 1991 to 2001.

Crown diameter and diameter of root collar (Fig. 3)

The development of mean crown diameter also indicates a growth-stimulating effect of applied limestone powder on the experimental spruce plantations. The limed plantations of spruce showed clearly higher values (statistical significance) of mean crown diameter than those of "control" variant. As far as the limed variants are concerned, the spruces of "planting pit" variant exceeded significantly those of "surface" variant. The evaluation of root collar diameter brought a conclusion that is analogous to the results of crown diameter.

Nutrition of plantations (Fig. 4)

Nitrogen. The application of limestone powder seems not to have had any negative effects on N supply to assimilatory tissues until now. The mean values of N content ranged between 1.17% ("surface" in 2000) and 1.70% ("surface" in 2001). The N supply of observed spruce plantations does not look optimal. Even if in 2000 only some values of N content dropped closely below the estimated limit of deficiency, nitrogen could belong among the limiting elements for spruce nutrition in future.

Phosphorus. Except for the content from 2000, the results of the analyses indicate that the supply to the spruce plantations could be sufficient for the time being. No significant differences in the development trend of P content have been found among the compared variants.

Potassium. An unfavourable trend of K content development seems to have ceased within all the variants after 2000. Even if the K content values from 2001 are adequate, we should not draw a conclusion that K supply already stabilised.

Calcium. Regardless of the variant, Ca supply seems to be sufficient for the time being. After their decrease in the period from 1994 to 1999, the values of Ca content have increased until now. The liming does not appear to have markedly influenced the Ca content in the spruce assimilatory tissues.

Magnesium. In 1994, the values of Mg content were markedly higher than those of the analyses made in the following years. It could be a random deviation or a result of a temporary influence of well-fertilised soil that could be contained in the root balls of spruce plants. Nevertheless, Mg contents have fluctuated closely above the limit of deficiency since 1996. Magnesium is a further element that could potentially limit the spruce nutrition in future. It is surprising that the liming did not increase the content of Mg in the spruce assimilatory tissues at least temporarily.

Sulphur. The S contents that are slightly increased have reflected the remaining pollution impact.

Foliar nutrient ratios. Regardless of the variant, it is possible to characterise all the evaluated ratios (N/P, N/K, N/Ca and N/Mg) as normal or adequate. The limits published by DE VRIES (1998) were used as criteria in this case.

Soil chemistry

For the purposes of this study, the outputs of the soil sampling method are presented whereas the samples are taken directly from the space of planting pits. This method allows mutual comparisons of the soil properties of all three variants. Nevertheless, this goal is achieved at the expense of sampling frequency (limited amount of soil in

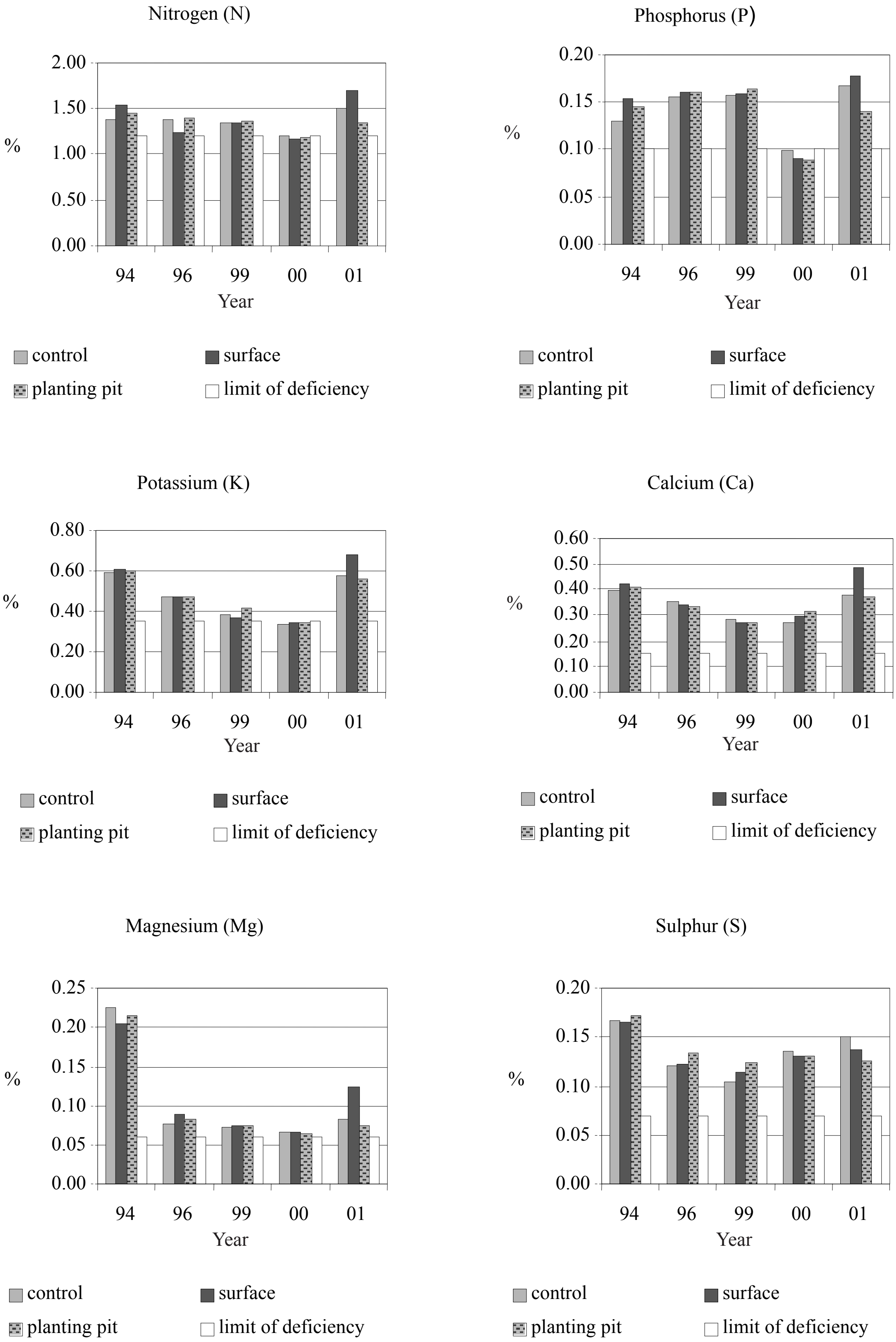


Fig. 4. Nutrition status of assimilatory tissues

Table 2. Basic pedochemical characteristics on particular variants

Year		1993			1998		
Variant		control	surface	planting pit	control	surface	planting pit
pH (H_2O)	–	4.25	5.75	6.38	4.10	4.40	5.70
pH (KCl)		3.41	4.90	5.66	3.50	3.80	5.70
S		16.20	70.00	83.50	3.60	6.90	21.90
H = T – S	(mval/100 g)	28.80	15.40	6.60	11.20	9.50	9.00
T		45.00	85.80	90.00	14.70	16.60	30.80
V		34.00	82.20	96.80	24.20	42.10	70.90
C_{tot}	(%)	18.50	12.60	12.60	4.10	4.20	4.80
N_{tot}		0.73	0.51	0.73	0.25	0.21	0.29
C:N ratio	–	25.00	25.00	17.00	16.00	20.00	17.00
P_2O_5					12.20	11.10	18.90
K_2O	(mg/100 g)				5.20	4.90	4.50
CaO					38.00	61.30	620.00
MgO					12.00	26.90	256.70

the space of planting pits). The soil properties from 1993 and 1998 are currently at disposal (Table 2).

Soil reaction. The pH values of "control" variant from 1993 as well as from 1998 indicate strong acidity of soil at the site. The application of dolomitic limestone powder increased both pH values (H_2O, KCl) markedly. The soil reaction was influenced to the largest extent by applications of dolomitic limestone in the planting pits. In the case of "planting pit" variant, the soil showed incommensurately high values of pH (H_2O) and pH (KCl) for the mountain site in 1993. The soil reaction of "surface" variant was lower than that of "planting pit" variant, nevertheless, it was also fairly high. The outputs of the soil analyses from 1998 pointed to the temporality of the effects of liming on the soil reaction. In spite of this fact, the pH (H_2O) values and pH (KCl) values of both limed variants were still apparently higher than those of "control" variant in 1998.

Characteristics of sorption complex. In fact, the "control" variant showed acceptable (for a mountain site) values of the sorption complex characteristics in 1993, however, in the case of limed variants these characteristics could be regarded as optimal for the development of forest tree species at that time. The soil base content "S" of "surface" variant was more than 4 times and that of "planting pit" variant even almost 5 times higher than the base content value of "control" variant in 1993. The soil analysis from 1993 indicated that the liming in both forms of its application markedly reduced the hydrolytical acidity "H" and increased the base saturation "V" to a level that was luxurious for the nutrition of forest tree species. The cation sorption capacity value "T" was also higher in the case of limed variants than the "T" value of "control" variant.

Five years later in 1998, the analysis indicated a diminution of liming effects on the sorption complex characteristics. A marked sag in the "S", "T" and "V" values was registered in limed variants. Nevertheless, the positive effect of liming on the sorption complex was still distinctly detectable, in spite of a reduction in the "S", "T" and "V" values that also occurred in the case of "control" variant. The diminution of the effects of liming was expectable but the sag in the "S", "T" and "V" values detected in "control" variant was surprising. It could be a consequence of excessive mineralisation due to the absence of forest cover or a random deviation of the data. To get the answer to this question a further analysis is necessary.

Total nitrogen and carbon contents. In 1993, the total carbon contents "C_{tot}" of limed variants were markedly lower than the "C_{tot}" value of "control" variant. In 1998, no considerable "C_{tot}" differences were registered by the variant comparison any longer, however, the values of all variants were markedly lower than those from 1993.

According to the analysis from 1993, the surface form of limestone application may have negatively influenced the "N_{tot}" content temporarily. In 1998, the difference in the "N_{tot}" values between the compared variants diminished. Unfortunately, this equalisation happened at the expense of "N_{tot}" amount that was substantially lower (in 1998) than the "general" level of "N_{tot}" amount in 1993.

A phenomenon of sag in the "C_{tot}" and "N_{tot}" values between 1993 and 1998 is detectable, which is analogous to that registered in case of sorption complex characteristics.

Contents of some mineral nutrients in soil. The contents of available P_2O_5, K_2O, CaO and MgO were analysed only in 1998, therefore no assessment of time development is at disposal. The analysis outputs indicate that the application of dolomitic limestone to planting pits increased the amount of available P_2O_5. Both forms of limestone application slightly decreased the content of available K_2O, on the other hand, the CaO and MgO contents were massively increased, namely in the case of "planting pit" variant.

DISCUSSION

As regards the applications of basic rock powders, it is of crucial importance not to draw premature conclusions.

Fig. 5. It is clearly visible that the ameliorated spruces in the background of the photo prosper better than those of control variant in the foreground (Photograph by KUNEŠ 2002)

For instance: in a more exposed section of the experimental plot Jizerka there is another spruce plantation where the application of basic rock powders is tested. No marked positive effects of chemical amelioration on the plantation prosperity were registered in that case (KUNEŠ 2001).

The conclusions presented by other authors are also frequently discrepant as to the effects of chemical soil amelioration in air-polluted mountain areas (MATERNA, SKOBLÍK 1988; PELC 1997; TESAŘ 1986). A reader of this paper could ask: "Why are the results of chemical amelioration experiments in the mountain conditions so inconsistent?" The answer to this question is very complicated. Not all the mechanisms are defined that can influence the final results of liming.

A very simplified explanation could be based on the fact that trees of mountain areas frequently grow in extreme conditions. The extremity of mountain sites sometimes threatens the survival ability of trees. The trees at extreme sites can be limited by several factors. At an extreme deforested site in the mountains, a young tree plantation could suffer not only from acid soil, nutrient deficiency and pollution impacts but also from extreme microclimate. Each of these factors can limit the plantation prosperity severely, even though the others are not as constrained. The "Law of the Minimum" says that the population prosperity is limited by a resource (factor) in the shortest supply. That means it is possible to improve soil conditions and nutrition of trees but the plantation cannot respond to this improvement in case it is limited for instance by climate. Of course, the "Effect of Partial Substitution" also exists within the interaction of site factors, which implies that an abundant supply of one factor can partially offset deficiency of the other. However, the sphere of applicability of this effect is very limited.

It is essential to evaluate the specific site conditions carefully during the process of decision-making whether to apply soil amelioration or not. Chemical amelioration is acceptable only when it is clear that acidity and nutrient deficiency are crucial factors limiting the plantation prosperity: therefore at least the analysis of assimilatory tissues and soil is necessary. It must also be apparent that the trees have a sufficient potential to respond to this type of stimulation positively and effectively. On all accounts, one should be aware of potential risks inherent in liming. The probability of potential negative impacts of liming increases with an increasing dose of finely ground limestone powder. On the other hand, it is necessary to apply such an amount of powder with such fineness that the initiation of desired positive changes could be feasible. PODRÁZSKÝ (1992, 1993) published papers on this subject.

The experiments aimed at reactions of some pioneer species to soil amelioration are established at present. The pioneer species are well acclimated to extreme conditions and therefore they are supposed to have the higher potential of sufficient positive reactions to additional fertilising. The fertilised pioneer trees could transform supplied nutrients into their biomass and then into their litter more effectively than the climax tree species and form a preparatory young-growth stand. This young-growth stand could stabilise the site, revive nutrient cycling and provide a shelter for climax species. In some pioneer species e.g. Carpathian birch (*Betula carpatica* WALDST. et KOCH) it is important to find out its reaction to an increase in the soil pH value at first. At climatically extreme sites, the additional fertilisation of pioneer species is considered to be a possible alternative to the experiments focused on the fertilisation of plantations of climax tree species.

CONCLUSIONS

For the time being, the results of observations within the framework of this experiment have indicated positive effects of chemical soil improvement on the prosperity of tested Norway spruce plantation (Fig. 5). Liming speeded up the growth of young spruces and limited their mortality. These facts could be very important because young spruce plants are subjected to any existing extremes in clear-cut areas and precisely applied liming could help them to overcome the stage in which they are most vulnerable to extreme conditions. As far as the impact of liming on the soil is concerned, the results indicate that long-term deforestation of the site could pose a substantially higher risk of organic matter losses than precisely applied liming in this particular case.

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Prosperita smrkové výsadby po aplikaci jemně mletého dolomitického vápence

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ABSTRAKT: Tématem příspěvku je posouzení vlivu cílené aplikace jemného dolomitického vápence na prosperitu výsadby smrku ztepilého (*Picea abies* L.) a na půdu v extrémních ekologických podmínkách Jizerských hor. V článku je zhodnocena mortalita výsadeb, jejich roční výškový přírůst, průměr v krčku, korunové průměry, živinová analýza a některé výstupy z půdních analýz. Data jsou shrnutím vybraných výstupů z pozorování za jedenáctileté období vývoje výsadeb na sledovaném stanovišti. Podle těchto výsledků se aplikace dolomitického vápence (1 kg na sazenici) na výsadbách zatím projevuje pozitivně bez vážnějších negativních dopadů na půdu stanoviště.

Klíčová slova: smrk ztepilý; Jizerské hory; vápnění; lesní půdy; půdní charakteristiky; chemická meliorace

Otázka vhodnosti vápnění v horských oblastech patří i v současnosti k aktuálním a zároveň i velice kontroverzním tématům. Možná pozitiva i rizika tohoto opatření jsou již dostatečně známa. Co ale současná lesnická praxe postrádá, jsou přesnější informace o tom, za jakých okolností k vápnění přistoupit a jakým způsobem jej provést, aby byla minimalizována možná rizika a zároveň posílena pravděpodobnost projevu pozitivních účinků vápnění. Výsadbový pokus, o němž příspěvek informuje, je součástí širšího projektu, který byl právě touto problematikou iniciován.

Experiment byl založen v roce 1991 na pokusné ploše Jizerka a sleduje vliv cíleného vápnění a formy jeho aplikace na prosperitu smrkové výsadby. Oplocená plocha se nachází na imisní holině v nadmořské výšce 960 m na Středním Jizerském hřebeni. Stanoviště je řazeno do lesního typu kyselá smrčina třtinová (8 K 2), hospodářského souboru 721 a pásma imisního ohrožení B. Průměrná roční teplota stanoviště se pohybuje mezi 4 až 5 °C a celkové roční srážky dosahují asi 1 470 mm. Horninové podloží je tvořeno biotitickou žulou, půdním typem je horský humusový podzol. Pokusná výsadba sestává z deseti čtvercových plošek (100 m^2), přičemž na každou z nich bylo vysázeno 50 tříletých sazenic smrku ztepilého (*Picea abies* L.) ve sponu 2 × 1 m. Vedle kontrolní varianty (4 plošky) byly založeny dvě vápněné varianty se třemi opakováními u každé z nich:

– Varianta s povrchovou aplikací dolomitického vápence, kde byla ke každé sazenici ihned po výsadbě aplikována vápencová moučka o hmotnosti 1 kg na povrch půdy v kruhu o průměru 1 m.
– Varianta s jamkovou aplikací dolomitického vápence, kde byla vápencová moučka o hmotnosti 1 kg promísena s půdou v jamce během výsadby na pokusnou plochu.

Hlavním cílem experimentu bylo zodpovězení otázky, zda může cíleně aplikované vápnění k jednotlivým mladým stromkům v extrémních podmínkách horské imisní holiny pozitivně ovlivnit vitalitu výsadby. To znamená, zda může mladým smrkům pomoci překonat šok z přesazení do extrémně nepříznivých podmínek a urychlit jejich vývoj v odrostlejší a odolnější jedince, aniž by došlo k projevu možných negativních dopadů. Další neméně důležitou otázkou bylo, jaká forma aplikace dolomitického vápence se ukáže jako účinnější.

Výsledky plynoucí z jedenáctiletého každoročního pozorování naznačují, že vápnění mělo na prosperitu výsadeb, alespoň dosud, výrazný pozitivní účinek. Ten spočívá v omezení celkové mortality za období 1991 až 2001 (obr. 1). V roce 2001 vykazovala kontrola 24,2% celkovou mortalitu, povrchová aplikace dolomitického vápence 9,4% a jamková aplikace 16,1% celkovou mortalitu. Výrazné je urychlení přírůstu aplikací dolomitického vápence. Hodnoty průměrného ročního výškového přírůstu periodního jsou u vápněných variant za období 1991 až 2001 podstatně větší než u kontroly (kontrola 100 %, povrchová aplikace 134 % a jamková aplikace 153 %). Běžný roční výškový přírůst a průměrný roční výškový přírůst periodní shrnuje pro období 1991 až 2001 tab. 1. Vývoj průměrné výšky mladých smrků u jednotlivých variant znázorňuje obr. 2.

Vápnění také podpořilo rozvoj korun mladých smrků: střední hodnota průměru korun byla v roce 2000 u varianty s povrchovou aplikací dolomitického vápence o 29 % větší než u kontroly a u varianty s jamkovou aplikací byla o 43 % větší než u kontroly. Rozdíl ve prospěch vápněných variant lze zaznamenat i u tloušťky kmínků (průměr při jejich bázi). V roce 1999 převyšovala průměrná tloušťka báze kmínků u povrchově vápněné varianty o 43 % hodnotu zaznamenanou u kontroly, varianta s jamkovou aplikací kontrolu v tomto parametru předstihla dokonce o 61 %. Mezivariantní srovnání hodnot korunových průměrů a tloušťky kmínků při jejich bázi shrnuje obr. 3.

Zastoupení sledovaných živin N, P, K, Ca, Mg a S v asimilačním aparátu mladých smrků se u kontroly a vápněných variant při srovnání v rámci jednotlivých let vzájemně nijak nápadněji neliší (obr. 4). Do budoucna nelze vyloučit, že odrůstající výsadby by mohly pocítit nedostatečné zásobení dusíkem, případně i hořčíkem a draslíkem.

Údaje o výškovém přírůstu, o průměrech korun i tloušťkách kmínků byly statisticky testovány a testovací statistika poukázala na signifikantnost rozdílů mezi kontrolní variantou a variantami vápněnými. Je ale na místě upozornit, že rozkolísanost rozptylů jednotlivých porovnávaných souborů, která plyne z přirozené variability jedinců i stanoviště v reálném prostředí, nezřídka částečně oslabila závěry testů statistické analýzy. Výrazný náskok vápněných variant při procentuálním srovnání však naznačuje, že vápnění prosperitu mladých smrků v dosavadním období skutečně pozitivně ovlivnilo, i když jeho účinky, jak se zdá, u obou vápněných variant již postupně odeznívají.

Podle dosavadních analýz nemělo vápnění na půdu při uvedených dávkách a výše definovaných způsobech aplikace zatím žádný výraznější negativní dopad, který by mohl mít dlouhodobější charakter (tab. 2). Daleko závažnější by mohl být případný pokles hodnot některých charakteristik sorpčního komplexu a snižování zásoby celkového půdního uhlíku a dusíku v čase, který naznačuje u všech tří variant porovnání výstupů analýzy z roku 1993 a 1998. Zatím není jasné, zda se jedná o nějaký trend, či zda je to pouhá náhodná odchylka dat. Se závěry v tomto směru je tedy třeba vyčkat až na další analýzy.

S ohledem na přírůstovou odezvu výsadeb lze prozatím hodnotit jamkovou aplikaci jako efektivnější formu použití, povrchově vápněné výsadby však zase vykazují poněkud nižší celkovou mortalitu. Nezanedbatelnou roli ve prospěch povrchové aplikace může hrát i menší náročnost co do realizace v provozních podmínkách.

Předkládané výsledky jsou nicméně předběžné a na konečné zhodnocení je třeba delší časový horizont.

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