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ASSESSING THE INFLUENCE OF THE *LUPINUS* GENUS IN THE BIOLOGICAL RECLAMATION OF SITES DEGRADED BY WHOLE-AREA DOZER SOIL TREATMENT

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Abstract

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The paper deals with possibilities of using the blue lupine (*Lupinus angustifolius* L.), white lupine (*Lupinus albus* L.) and garden lupine (*Lupinus polyphyllus* Lindl) in the biological reclamation of sites degraded by whole-area dozer soil treatment.
The lupines were sown into strips or broadcast. The effect of lupines onto the growth and health condition of the young plantations of Norway spruce, European beech and Scots pine was studied together with their influence on the site soil characteristics. The experiment showed that the sowing of lupine favourably affected biometrical characteristics of newly planted trees. Even though the soil humus content did not increase in the experimental period of 5 years, the nitrogen nutrition as well as the nutrition with other biogenic elements improved and the symptoms of chlorosis were eliminated. In the conditions of the Krušné hory Mts., the lupines can produce up to 3.6 tons of biomass dry matter and favourably affect the nutrition of planted trees.

Norway spruce, Scots pine, European beech, lupine, biological reclamation, dozer soil treatment, humus, mineral nutrition

The Krušné hory Mts. (Ore Mts.) were affected by a severe air-pollution calamity in the second half of the 20th century, which resulted in a rapid and whole-area disintegration of spruce stands in particular. In the effort to reforest the extensive areas clear-cut due to air pollution, the method of whole-area dozer soil treatment was used in this region on more than 4 thousand hectares of forest (VRABEC, 1988; KUBELKA *et al.*, 1992). With this technology, the upper humus layer was many a time piled up insensitively into linear mounds, which resulted in forest site degradation. The removal of forest litter as the most important forest soil component disturbed the cycle of nutrients and led to subsequent disturbances in the growth of forest trees. The health condition of the stands of substitute tree species growing on these sites is unsatisfactory at present (KULHAVÝ *et al.*, 2000; MAUER *et al.*, 2004, 2005) and this is why reconstructions and conversions of these stands were started from the beginning of the 1990s. First a specified type of felling or clearing tree species growing on linear mounds (windrows) was usually done. Organic matter from the mounds was spread into intermediate strips in order to improve nutrition. However, the often applied lengthwise spreading of organic mineral mounds could not revitalize the whole stand area because the organic matter was usually spread into strips of varying breadth covering only about a half of the reconstructed stand area. Spreading of organic mineral mounds to sides at which humus layers can be returned onto the entire stand area started to be used only later. The procedure is however effective only on sites with large mounds through the spreading of which a sufficiently thick humus layer can cover the entire stand area. This is why the revitalization by the lengthwise or lateral spreading of mounds is not feasible on many sites due to lacking funds or due to scarified strips between the mounds underplanted in previous years.

One of possibilities to revitalize such stands (strips between unspread mounds) is the biological soil reclamation by using green fertilization aiming at the supply of organic matter, nitrogen and making available nutrients from the lower soil layers. The source of organic matter can be any kind of plants that are capable of giving as much organic matter and required effects as possible in the shortest possible time (MAREŠ *et al.*, 1961). An irreplaceable role in the biological reclamation is that of legumes for their considerably high biomass production and capacity to bind actively the atmospheric nitrogen. According to some literary works (MAREŠ *et al.*, 1961), some lupine species can create the above-ground part of up to 150 cm in height with the root system reaching down to a depth of 2 m, thus being able to produce up to 3.5 tons of biomass per hectare, with up to 40 kg bound nitrogen. Thus, it is assumed that the growing of lupine could increase the content of nitrogen available to plants, whose deficiency is high on these sites (VAVŘÍČEK, 2004), to enhance microclimatic conditions for newly planted crops and to contribute also to partial humus layer restoration. However, there are no data available today about the possibilities of using lupine for the biological reclamation of degraded sites in the concerned conditions and altitudes.

The work aimed at assessing the possibilities of using the *Lupinus* genus for the biological reclamation of sites degraded by whole-area dozer soil treatment and at studying its effects on the growth of newly planted forest tree species and basic soil characteristics.

MATERIAL AND METHODS

Material

The biological reclamation was made with the following five varieties of blue lupine (*Lupinus angustifolius* L.) – Prima, Sonet, Gallant, Rose and Viol, four varieties of white lupine (*Lupinus albus* L.) – Amiga, Dieta, Vollos and Olezhka, and with the garden lupine (*Lupinus polyphyllus* Lindl). Results of our research were evaluated not by the varieties but rather by the species.

Methods

Establishment of experimental plots

Two experimental plots were established on the property of Chomutov Municipal Forests in stands with the whole-area dozer soil preparation during which nearly the entire humus layer was removed by the smooth edged dozer blade.

Plot A

The plot is situated on the St. Sebestian Mt. in Stand 521 C2 at an altitude of 870 m a.s.l. The soil type is deeply scarified Haplic Podzol on binary paragneiss. At the beginning of the year 2006, a stand of blue spruce was cut on the plot and the wood mass was removed. This gave rise to a clear-cut area sized ca. 0.85 ha (40 × 210 m) with its longer axis oriented to east-west and with unspread mounds of about 2m in height left on the sides. The plot was fenced and divided into 10 parcels of which two were not sown with the lupine and served as a control.

In 2006, the parcels were sown with the blue lupine varieties Prima, Sonet, Gallant, Rose and Viol, with the varieties of white lupine Amiga and Dieta and with the garden lupine. On four parcels, small strips were created on the weeded soil into which the seed was sown by hand to a depth of 2 cm under the ground surface. The distance between the strips was 20 cm and the spacing of individual seeds was 5 cm. Other four parcels were sown by spreading the lupine seeds over the untreated soil surface. The sowing rate in the first experimental year was 150 $kg.ha^{-1}$; in the other years, it was increased to 200 $kg.ha^{-1}$ with taking into account the applied method of sowing the seeds by spreading over the soil surface. Subsequently, bare-rooted Norway spruce transplants were planted into holes on all parcels.

In 2007, point fertilization with NPK at 100 $kg.ha^{-1}$ was applied to all planted trees on the half of the parcels (including one control parcel).

Plot B

The plot is situated on the St. Sebastian Mt. in Stand No 521 C2 at an altitude of 870 m a.s.l. The soil type is Haplic Podzol on binary paragneiss, scarified to a shallow depth. At the beginning of the year 2010, a stand of blue spruce was cut on the plot and the wood mass was removed. This gave rise to a clear-cut area sized ca. 0.18 ha (38 × 46 m). Unspread mounds of about 2 m in height remained on the sides and in the middle of the clear-cut area. The plot was fenced and divided into 7 parcels of which two were left without the sowing of lupine and served as a control.

In 2010, the plot was sown by spreading the lupine seeds on the ground surface. The sowing rate of blue lupine (var. Rose and Viol) and white lupine (var. Amiga, Vollos and Olezhka) was 200 $kg.ha^{-1}$. In 2011, bare-rooted transplants of European beech (*Fagus sylvatica* L.), Norway spruce (*Picea abies* /L./Karsten) and Scots pine (*Pinus sylvestris* L.) were planted into holes on the plot by hand and the lupine varieties were repeatedly sown.

Assessing the growth, vitality and damage of the planted trees

All plants on the plots were screened for lots parameters and features of which 3 parameters were established by exact measurement and 6 features by visual evaluation. The monitoring included a minimum number of 90 trees in each experimental variant. The monitored parameters and features were as follows:

- total height (measured with accuracy to 1cm)
- terminal shoot increment (measured with accuracy to 1 mm)
- root collar diameter (measured with accuracy to 1 cm)
- vitality (evaluated by four grades according to the colour of assimilatory organs: 1-green, 2-yellowish, 3-yellow, 4-dying plant; the tables present arithmetic means of all values from each parcel)
- stem form (evaluated by three grades: P-straight terminal shoot, D-forked terminal shoot, V-multiple terminal shoot – three and more equal shoots of the same diameter)
- plant damage (presence or absence of damage to plants by wildlife, frost or mechanical damage – two following types of damage were classified:
  - damage to plant terminal (browse – damage to terminal bud by browsing, dry top – recorded in the case of dead terminal bud or entire terminal shoot)
  - damage to plant sides (damage to branches and stem); two following types of damage were classified: browse on sides – damage by game browsing to more than 20% of all lateral branches, and frost – damage to assimilatory organs by frost
- chlorosis – colour changes of needles (yellowing); for being recorded, more than 20% of all needles on the plant had to show the damage.

Collection and processing of needles

In order to establish the effect of biological reclamation on the nutrition of the spruce transplants, three composite samples were taken of 1-year needles from the upper third of crowns of at least eight trees on the control plot A at the end of the growing season 2011. The same method was used to take three composite samples of needles from the plots ameliorated by the garden lupine. The needle samples were analyzed by the accredited laboratory Morava, s. r. o. in Studénka. The contents of N, P, K, Ca and Mg were established after wet mineralization. Total nitrogen (N_t) was established by the coulometric method, P content by the spectrophotometric method, Ca and Mg contents by the method of atomic absorption spectrophotometry and K content by the method of atomic emission spectrophotometry.

Evaluation of lupines

Aiming at an exact evaluation of the lupine emergence rate in different sowing methods, we staked 10 parcels on the plot B, sized 1x1m that were each sown with 100 seeds either in small strips 2 cm under the soil surface or by spreading onto the untreated ground surface.

The theoretical number of plants potentially growing on the area of 1ha after seeding by spreading on the soil surface was derived from the emergence rates and absolute seed weights.

During the research, lupine samples were taken to determine the production of dry matter. A minimum of 100 plants were taken by random from each lupine species or variety, which were divided into the above-ground part, root system and fruits. Their dry weight was established after desiccation to constant weight.

Collection and processing of soil samples

At the end of the growing season 2011, three composite soil samples were taken on the plot A from the control parcel and from the parcel ameliorated by the garden lupine directly from root balls, each from five planted spruce trees. The same method was used to take samples on the plot B (from the control parcel and from the parcels ameliorated by the blue and white lupines). We established the active (pH/H_2O) and the potential (pH/KCl) soil reaction. The cation exchange capacity (KVK), the content of exchangeable bases (S) and basic saturation (BS) were established by the modified Kappen method (KLETCHKOVSKIY and PETERBURSKIY, 1964). Available mineral nutrients were established by the method of atomic absorption spectrophotometry in the Mehlich II extract (MEHLICH, 1978).

Apart from the total soil nitrogen content (N_t), we monitored the movement of mineral nitrogen across the soil profile. Ion exchangers were installed beneath the root balls at a depth of ca. 15–20 cm. The ion exchangers were made of Novodur (unsoftened PVC) rings (diameter = 70 mm, thickness = 4 mm) covered with the polyamide mesh UHELON (Silk&Progress, Type 130, eye size 42 µm). The NH_4^+-N and NO_3-N concentrations were established after desorption of these ions in the NaCl solution. The amount of desorbed ammonia nitrogen was determined by the spectrometric method with salicylate and chlorate in the presence of sodium nitrosopentacyanoferrite (CSN ISO 7150-1, 1994). Nitrate nitrogen was established by the modified spectrometric method with sulphosalicylic acid (CSN ISO 7890-3, 1994). Yield coefficients for NO_3^- and NH_4^+ desorption were ascertained in the laboratory.

Statistical evaluation

The measured parameters of the above-ground part of young trees were statistically analyzed in the Statistica 9.0.CZ programme using one-factor Anova for files with the identical number of elements. The significance level was set up at $\alpha = 0.05$. The average values were calculated by using the method of least squares. The significance of statistical differences of the individual parameters was verified by the Dunnett test (comparison with the control) and by the Duncan test procedure. The measured data were tested for the normality of distribution. If the normality was disturbed, the data were transformed.

The normality of data from the soil and leaf analyses was analyzed by the Shapiro-Wilks test and the homogeneity of variances was tested by using the Bartlet test. Regarding the fact that the conditions for using the parametric tests were not complied with, the effect of different lupine species on soil environment characteristics was evaluated by using the Kruskal-Wallis ANOVA with differences between the individual variants being ascertained by means of multiple comparison. All hypotheses were evaluated at a significance level of $\alpha = 0.05$.

RESULTS

The influence of lupine on the growth of young trees

On the plot A where it had been sown since 2006, the lupine showed its positive (yet not statistically significant) influence on the growth parameters and vitality of planted young spruce trees already in the following year (Tab. I). Compared with the control without the sown lupine, the significance of differences was however increasing with the proceeding time. In the second year after planting (2007), symptoms of chlorosis were observed to occur on the assimilatory organs of spruce trees on all parcels. Tab. I shows a clearly positive influence of the cultivation of all lupine species on the reduced occurrence of this undesirable phenomenon. In 2008 and 2009, the chlorosis occurred more massively only on the control parcels; spruce trees on a majority of parcels with the sown lupine did not show the symptom. The differences were statistically significant in the absolute majority of cases. In searching the causes of the deficiency phenomena, leaf analyses revealed considerable differences in the nitrogen content of one-year needles. While the needles of spruce trees on the control plots contained only 1.05% N, the content of nitrogen found in the needles on the plots ameliorated by the lupine was 1.3% (Tab. II), which signalled the optimum N-nutrition. The difference between the controlled and ameliorated plants showed in the Ca-nutrition, too (Tab. II); the lower values in the control (6.2 $g.kg^{-1}$) and the higher values on the lupine-ameliorated parcels (7.4 $g.kg^{-1}$) were at the level of very good nutrition. Lupine reduced the nutrition of spruce with magnesium (Tab. II) from a slightly luxurious supply in the control (1.35 $g.kg^{-1}$) to an optimum, non-antagonistic boundary (1.0 $g.kg^{-1}$). While the potassium content in the spruce needles (Tab. II) was below the lower optimum level (4.6 $g.kg^{-1}$) on the control parcels with the luxurious Mg supply, on the lupine-ameliorated parcels it increased to the level of favourable nutrition (5.5 $g.kg^{-1}$). The content of phosphorus that was at the lower optimum level on the control parcels (Tab. II) increased to the optimum level (1.4 $g.kg^{-1}$) on the lupine-ameliorated parcels. The cultivation of lupine did not largely affect either the shape of plants or their damage by wildlife or frost (Tab. I). The same table shows that the point NPK fertilization of spruce trees in the second year after planting (2008) positively reflected in the condition of the trees in the whole study period (until 2009) and stimulated the growth of lupine in the whole study period, too (Tab. III).

After five years of the influence of lupines, the humus content in the spruce rhizosphere did not increase. On the control parcel as well as on the lupine-ameliorated parcels, the humus content ranged at a level of humous soil (4.7%), which is documented by the identical C content (3.7%) on the ameliorated and control parcels. Nevertheless, the cultivation of lupine increased the content of total soil nitrogen as compared with the control parcel by about 0.02%, which also reflected in the improved C/N ratio. However, the difference was not statistically significant.

As to its dynamics, total soil nitrogen (N_t) is a parameter of little significance for nutrition. Decisive is the content of its mineral fractions whose eluviation in the soil was significantly buffered by the root systems of the lupines. Nitrate nitrogen in particular was sorbed on the parcels sown with the lupine (Fig. 1).

The soil exhibited high contents of bivalent cations (apparently due to previous liming). The cultivation of lupine in the acidic ecological series reduced the medium-high content of calcium from 420 $mg.kg^{-1}$ to acceptable ca. 280 $mg.kg^{-1}$ and for the given edaphic category extremely high magnesium content from 130 $mg.kg^{-1}$ to a still high content of 70 $mg.kg^{-1}$. The content of potassium did not change and the content of available phosphorus remained at a relatively low level.

In 2011, i.e. in the first growing period after planting, and after the second year of lupine cultivation, young trees on the plot B were still under a partial influence of the previous nursery cultivation. Therefore, no clear differences were found between the control and the ameliorated parcels (Tab. IV). In spite of the fact, a positive influence of lupine cultivation on the increment and vitality of young trees can be observed in all three valuated tree species. The statistical significance of results was low, however.

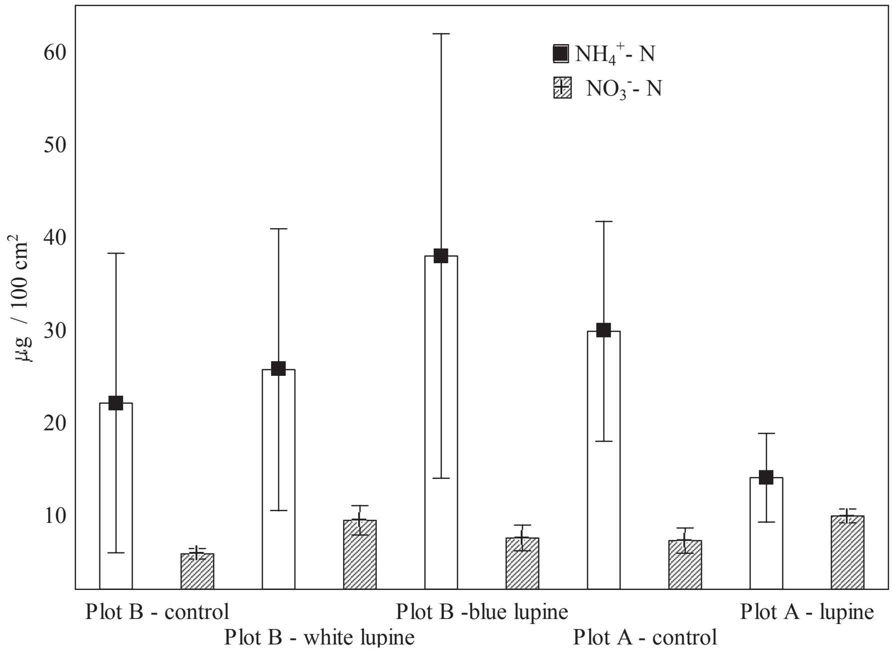
Soil analyses showed a relatively low cation exchange capacity (110–120 $mmol.kg^{-1}$) on all parcels. The humus content in the rhizosphere on the control parcels as well as on the parcels improved with the narrow-leaved and white lupines ranged from 6.2–6.5% and did not change after the second year of the lupine cultivation, which documents identical carbon contents. The sown lupine significantly affected the content of total nitrogen, which increased to medium-high (0.19%) already after two years of the lupine cultivation as compared with 0.16% on the control parcel; the difference was however insignificant. Although the hitherto short-term cultivation of lupine did not increase the

I: *The effect of biological amelioration on the growth and vitality of spruce (Plot A)*

Year of measure-ment	Lupine	Fertilizer	Total height (cm)	Increment (cm)	Root collar diameter (mm)	Vitality	Stem form in the year of measurement (% of plants)			Damage to plants (%)				Chlorosis (% of plants)
										Terminal		Lateral		
							Straight	Fork	Multiple	Browse	Dry top	Browse	Frost	
2007	white	No	32.6 ± 4.5	1.9 ± 1	7.3 ± 1	2.0	100.0	0.0	0.0	0.0	0.0	0.0	2.8	0.0
	blue	No	31.8 ± 3.9	2.5 ± 1+	7.5 ± 1	1.5+	92.9	0.0	7.1	0.0	2.4	0.0	7.1	0.0
	garden	No	31.9 ± 4.2	2.4 ± 1+	7.8 ± 1+	1.5+	97.0	3.0	0.0	0.0	12.1	0.0	6.1	0.0
	control	No	31.7 ± 4.4	0.7 ± 0	6.7 ± 1	2.2	96.4	0.0	3.6	0.0	3.6	0.0	0.0	0.0
	white	Yes	33.6 ± 4.7	1.4 ± 1	8.1 ± 2+	1.0+	91.7	0.0	8.3	0.0	0.0	0.0	0.0	4.2
	blue	Yes	30.2 ± 4.5	2.2 ± 1+	7.1 ± 2	1.0+	100.0	0.0	0.0	0.0	0.0	7.1	3.6	0.0
	garden	Yes	32.3 ± 5.0	1.1 ± 1	7.4 ± 1	1.1+	97.1	0.0	2.9	0.0	5.9	0.0	2.9	0.0
	control	Yes	30.0 ± 5.0	1.3 ± 1	7.2 ± 1	2.0	96.2	0.0	3.8	0.0	0.0	0.0	0.0	0.0
2008	white	No	40.5 ± 6.7	9.1 ± 5.0+	9.8 ± 2.1	1.7+	100.0	0.0	0.0	2.7	2.7	2.7	0.0	18.9+
	blue	No	40.9 ± 7.3	8.7 ± 4.6+	10.0 ± 2.4+	1.8+	98.1	1.9	0.0	0.0	0.0	0.0	0.0	33.3+
	garden	No	40.5 ± 7.9	7.9 ± 4.3	10.1 ± 1.9+	2.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0+
	control	No	38.8 ± 10.1	4.7 ± 4.1	8.4 ± 1.5	2.3	96.4	3.6	0.0	0.0	3.6	0.0	0.0	46.4
	white	Yes	46.8 ± 6.4+	14.8 ± 4.5+	10.5 ± 2.1+	1.4+	100.0	0.0	0.0	0.0	0.0	0.0	0.0	8.3+
	blue	Yes	46.4 ± 7.7+	12.5 ± 4.9+	11.4 ± 2.9+	1.1+	100.0	0.0	0.0	0.0	0.0	0.0	0.0	9.5+
	garden	Yes	42.3 ± 6.1+	10.3 ± 4.2+	10.4 ± 2.1+	1.9	96.9	0.0	3.1	3.1	0.0	0.0	0.0	18.8+
	control	Yes	34.6 ± 6.9	4.4 ± 3.4	8.2 ± 2.0	2.4	96.0	4.0	0.0	0.0	0.0	0.0	0.0	32.0
2009	white	No	50.1 ± 8.2	8.9 ± 4.4	14.1 ± 2.4+	1.9+	98.2	1.8	0.0	31.6	0.0	1.8	0.0	0.0+
	blue	No	50.3 ± 9.3+	9.5 ± 4.5+	14.1 ± 2.6+	1.9+	86.8	10.5	2.6	44.7	0.0	0.0	0.0	5.3
	garden	No	47.3 ± 10.3	9.1 ± 5.8+	13.9 ± 2.9	2.1	100.0	0.0	0.0	28.0	0.0	4.0	0.0	0.0+
	control	No	43.9 ± 8.7	7.0 ± 5.6	12.0 ± 2.9	2.3	96.6	3.4	0.0	0.0	0.0	0.0	0.0	26.9
	white	Yes	61.2 ± 9.8+	15.0 ± 5.6+	15.5 ± 2.5+	1.9	100.0	0.0	0.0	33.3	0.0	12.5	0.0	0.0+
	blue	Yes	56.7 ± 8.1+	14.0 ± 4.9+	15.2 ± 2.4+	1.3+	92.0	8.0	0.0	52.0	0.0	24.0	0.0	0.0+
	garden	Yes	51.3 ± 11.6+	10.7 ± 5.2+	12.6 ± 2.2	1.4+	97.0	3.0	0.0	9.1	0.0	9.1	0.0	12.1+
	control	Yes	40.3 ± 10.9	4.1 ± 4.5	11.3 ± 2.8	2.1	100.0	0.0	0.0	0.0	0.0	0.0	0.0	29.0

II: *Contents of biogenic elements in 1-year spruce needles after 6 years of biological amelioration with lupine*

Variant	P (g.kg⁻¹)	Mg (g.kg⁻¹)	Ca (g.kg⁻¹)	K (g.kg⁻¹)	N (%)	S (g.kg⁻¹)
Lupine	1.44 ± 0,02	1.07 ± 0,01	7.37 ± 0,02	5.43 ± 0,02	1.36 ± 0,01	0.79 ± 0,02
Control	1.36 ± 0,03	1.36 ± 0,04	6.21 ± 0,02	6.64 ± 0,01	1.07 ± 0,02	0.81 ± 0,02



1: *Ammonia and nitrate nitrogen in the soil under spruce root systems on the control parcels and on the parcels ameliorated by lupine*

III: *Biomass dry matter and the potential production of lupines used in the experiment (Plot A)*

Year of measurement	Lupine	Fertilizer	Dry weight (g . plant ⁻¹)				Potential number of plants (thous.ha ⁻¹)	Potential total dry matter (kg.ha⁻¹)
			Pod	Above-ground part	Root system	Σ		
2007	blue	Yes	1.580	1.587	0.289	3.456	973.0	3 362.6
		No	0.696	0.880	0.164	1.741	973.0	1 694.0
	white	Yes	0.237	3.976	0.712	4.926	506.0	2 492.3
		No	0.248	2.733	0.505	3.486	506.0	1 763.9
2008	blue	Yes	1.853	1.300	0.229	3.382	973.0	3 290.6
		No	1.595	1.141	0.170	2.906	973.0	2 827.9
	white	Yes	0.326	4.030	0.783	5.139	506.0	2 600.3
		No	1.096	1.788	0.424	3.308	506.0	1 673.8
2009	garden	No					103.0	0.0
2010	blue	No	0.847	1.247	0.228	2.323	973.0	2 259.8
	white	No	1.948	4.628	0.629	7.205	506.0	3 645.7
2011	blue	No	0.759	1.296	0.264	2.319	973.0	2 256.2
	white	No	0.765	2.639	0.292	3.696	506.0	1 870.2

amount of humus, it showed in its quality expressed by the C/N ratio, which decreased to the efficient values 17–18. The content of available nutrients on all parcels of the plot B was equable and the effect of biological amelioration was not showing yet.

During the monitoring, the samples of the cultivated lupines were taken each year for the assessment of the produced biomass. Tab. III shows that the complementary NPK fertilization of the parcels positively reflected in the production of biomass already in the second year after the application. As a rule, the white lupine produced a greater amount of biomass.

The plot B was studied also for the different emergence rate of lupine seeds in the different sowing methods – into the prepared soil and by spreading onto the untreated soil surface. Tab. V indicates that the difference in the emergence rate between the two methods ranged (in all used lupine species) only within 10–16%.

DISCUSSION

The inconsiderate dozer soil treatment in the Krušné hory Mts. resulted in a more or less complete removal of the humus layer and to subsequent problems with the development of the stands of substitute tree species, which on these sites showed colour changes of assimilatory organs, low vitality and extremely flat and superficial root systems (MAUER *et al*., 2004, 2005). The situation did not change even after about thirty years from the soil surface scarification and the sites featured only the initial layer of raw humus. In the reconstruction of substitute woody species stands, the deficient humus is compensated for by the spreading of linear mounds (POP, 2007; VAVŘÍČEK, 2010). Another possibility of soil enrichment with organic matter is biological reclamation with using the *Lupinus* genus. Numerous species and varieties are available that differ in both ecological requirements and in the production of biomass.

Different varieties of blue and white lupines and the garden lupine were used on the experimental plots. The blue lupine is considered as less warm-requiring and suitable for harsh climate. According to KOUBOVÁ (2004), blue lupine yields ranged from 1.86 to 4.16 $t.ha^{-1}$ in dependence on the year and site in the variety trials conducted in Germany in 2001–2003. In the average of three years, yields on sites with loess, eolian sandy soils and diluvial soils amounted to 3.6, 3.1 and 2.6 $t.ha^{-1}$, respectively. Our research indicates that on the degraded sites in the Krušné hory Mts., the blue lupine achieved the production of max. 1.5 $t.ha^{-1}$. About a third of its biomass weight was formed by pods, resp. seeds. A question is to what extent the enhancing effect of this component would ever show because the lupine seeds are a sought feed source for many animal species and this is why considerable losses can be expected. If the seeds are not taken into account within the total amount of the produced biomass, the amelioration potential of white lupine is higher than that of blue lupine. A positive phenomenon is the fact that the white lupine develops a larger root system penetrating to greater soil depths.

The main goal of sowing the lupine was to enrich the degraded sites with organic matter that would speed up the restoration of the humus layer. Analyses of soil samples taken from parcels with the lupine as compared with parcels that had not been biologically improved showed that the amount of humus did not essentially change after five years and remained at ca. 4.7% on the plot A, which is insufficient for both the organic mineral and the organic horizons. The biomass was apparently rapidly mineralized without contributing to the production of active humus and forest floor. After two years of lupine cultivation, no improvement could be expected on the plot B either.

Although the five year cultivation of lupine did not increase the amount of humus, it favourably affected the nutrition of planted spruce trees, namely due to the soil enrichment with nitrogen. In spite of the fact that the increase is not statistically significant due to a great variance of values, its effect on the nutrition and vitality of plants is beyond any dispute. The scarified plots were in the past limed with dolomite limestone due to which they exhibit high contents of calcium and particularly magnesium, and at the same time a deficient content of nitrogen. The determined N/Mg ratio in one-year needles (7.7) of control spruce trees signalled an unbalanced nutrition (ŠRÁMEK *et al*., 2009). The lupine cultivation suppressed the contents of basic elements in the soil to a more favourable level since within the antagonism of bivalent and monovalent elements, it is not only potassium that is forced out from the sorption complex at a high Mg content, but also ammonia nitrogen, which is preferred by conifers in their nutrition (AARNES *et al*., 1995; VAVŘÍČEK, 2006).

In the second year after planting, the young spruce trees began to show symptoms of chlorosis. The apparent reason was nitrogen deficiency since the chlorosis symptoms on the parcels with the lupine gradually ceased while they persisted on the control parcels. The leaf analyses demonstrated the increased content of nitrogen in one-year needles to 1.35% as compared with 1.05% in the control spruce plants. Another reason for the chlorosis might be the blocking of nitrogen by the luxurious nutrition with magnesium the content of which in one-year needles reached 1.35 $mg.kg^{-1}$ while the magnesium content in spruce plants on the parcels with the lupine was optimal at 1.07 $mg.kg^{-1}$. The increased N content with the simultaneously decreased Mg content in one-year needles led to the optimal N/Mg ratio.

Another interesting finding is the long-term positive response of spruce trees and all lupines to the application of NPK fertilizer. The effect was still recorded three years after the application. The question is, however, whether the enhanced growth of spruce plants for the entire experimental period resulted from the complementary fertilization itself or whether the fertilizer application primarily increased the production of lupine biomass thanks to which the site soil parameters were improving in the following years. This question could be answered by further research of the issue.

In addition to the positive effects on the soil characteristics, growth and vitality of Norway spruce (*Picea abies* /L./ Karsten), the lupine can provide a shelter for new plantations. In this respect, the

IV: *The effect of biological amelioration by lupine on the growth of young beech, spruce and pine plantations (Plot B)*

Species	Lupine	Total height in 2011 (cm)	Increment in 2011 (cm)	Root collar diameter 2011 (mm)	Vitality *	Stem form in the year of measurement (% of plants)			Damage to plants (% of plants)			
									Terminal		Lateral	
						Straight	Fork	Multiple	Browse	Dry top	Browse	Frost
Beech	white	51.2 + 5.4+	8.7 ± 3.9+	9.0 ± 1.1	1.3	97.0	0.0	3.0	0.0	3.0	0.0	0.0
	blue	48.0 ± 6.2	6.7 ± 2.9	8.5 ± 1.5	1.4	100.0	0.0	0.0	3.3	6.7	0.0	0.0
	control	44.6 ± 6.1	6.5 ± 3.5	8.8 ± 1.5	1.4	100.0	0.0	0.0	0.0	4.1	3.1	3.1
Spruce	white	29.8 ± 3.5	8.6 ± 1.9+	7.5 ± 1.1	1.8	1.0	0.0	0.0	0.0	0.0	0.0	0.0
	blue	30.9 ± 3.5	7.9 ± 2.5	5.8 ± 0.9	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
	control	30.7 ± 5.2	7.6 ± 3.4	6.9 ± 1.2	2.2	1.0	0.0	0.0	0.0	0.0	0.0	0.0
Pine	white	10.5 ± 3.6	3.3 ± 2.2	3.4 ± 0.8	1.3	100.0	0.0	0.0	0.0	0.0+	0.0	0.0
	blue	12.4 ± 3.4	4.5 ± 2.6+	3.9 ± 0.7	1.3	97.4	2.6	0.0	0.0	0.0+	0.0	0.0
	control	11.9 ± 3.3	3.1 ± 2.3	3.8 ± 0.8	1.6	97.2	0.0	2.8	2.8	5.6	2.8	2.8

V: *Emergence rate of lupine seeds in dependence on the sowing method*

Lupine	Germinating plants (%)		Difference (%)	Sowing rate (kg. ha^{-1})	Absolute weight of seeds (g)	Potential number of plants (thous.ha^{-1})
	Sowing into prepared soil	Broadcast on the soil surface				
blue l	88	72	16	200	148	973
white	98	88	10	200	348	506
garden	71	55	16	30	28.3	583

white lupine surpassed the narrow-leaved lupine in a majority of cases and produced the above-ground part larger by about a third (some varieties even by 60 cm). The narrow-leaved lupine did not meet the expectations particularly in the first year as its above-ground part reached only to about 2/3 of the total height of planted young trees and its capacity to provide a shelter for the new plantations was practically zero. In the second year, the growth of the narrow-leaved lupine improved as compared with the first year and the plants provided an efficient shelter for the young trees. The white lupine fully shielded the planted young trees already from the first year and the garden lupine started to provide an efficient shelter only in the second year. Nevertheless, all three lupine species reached in their growth the lower limit of the range quoted in literature; e.g. MAREŠ *et al.* (1961) informs that one-year lupines reach a height of 50–100 cm and the garden lupine reaches up to 150 cm.

For green fertilization, the lupine seeds are usually sown into the pre-treated soil in rows 2–3 cm under the soil surface, which is unrealistic in the ameliorated young forest plantations. This is why the classical agricultural procedure was compared with the sowing of a known number of seeds by manual spreading. The emergence rate of the seeds sown by spreading without the soil treatment was only by 10–16% lower in the respective lupines and a slight increase of the sowing rate can apparently help to achieve a comparable yield.

The verification was made with the varieties of blue and white lupines that are annual while the garden lupine is perennial. Although the pods of annual species formed a third of the produced biomass, their spontaneous reproduction was recorded not even once; the seeds were apparently damaged either by rodents or by fungal diseases during the winter period.

The garden lupine showed spontaneous distribution of plants already in the third year after sowing. Since the species hates shading, it usually disappears from the stand after its closure. Interesting is also the fact that probably also due to the production of seeds as an attractive feed for mice, only a very low damage on young plantations by *Muridae* rodents was recorded on the plots with the lupine during the whole period of study although considerable damages repeatedly occurred in adjacent stands.

Our research shows that lupine may play an important role in the revitalization of plots degraded by the whole-area dozer soil preparation. In spite of the fact that it apparently does not contribute largely to the restoration and increase of the humus layer, by supplying the deficient nitrogen it can stimulate the growth and vitality of young plants and thus to increase the amount of litter and become a source of nitrogen for micro-organisms participating in humification.

CONCLUSIONS

Main conclusions following out from the assessment of the effect of biological amelioration with lupine on some soil characteristics and on the growth of young plantations of Norway spruce, European beech and Scots pine on sites degraded in the past by whole-area dozer soil preparation are listed below:

- Biological amelioration with lupine positively affected the growth parameters (height, increment, root collar diameter) of planted spruce trees.
- Lupine suppressed or even eliminated significantly the symptoms of chlorosis in Norway spruce as compared with the control.
- Biological amelioration with lupine positively affected the spruce nutrition (statistically significant increase of N content in one-year needles, decreased Mg content and K and P contents increased to optimal threshold level).
- Complementary point fertilization of spruce trees with NPK positively reflected in the condition of spruce as well as in the growth of lupine for the entire period of study.
- Repeated sowing of lupine for the period of 5 years neither essentially increased the humus content nor supported the development of humus forms; nevertheless, it enhanced the quality of humus as such (decreased C/N ratio).
- Biological amelioration with lupine relatively increased the total soil nitrogen.
- Lupine can be sown by manual spreading. Differences in the emergence rate of seeds of all lupines between sowing into the pre-treated soil and manual spreading onto the soil surface ranged within 10–16%.

SUMMARY

The removal of the forest floor during the whole-area dozer soil treatment in the Krušné hory Mts. at the end of the last century resulted in the disrupted cycling of nutrients and impaired growth of planted trees. In the reconstruction of substitute tree species stands, the humus layer is restored by spreading linear organic mineral mounds. The work was to verify an alternative procedure for the revitalization of degraded soils through biological amelioration with lupine and to ascertain its effect on the growth of spruce, beech and pine (tree height, increment, root collar diameter, vitality, damage by biotic and abiotic agents and contenst of basic nutrients in one-year needles), and on the fundamental soil characteristics (humus content, C content, C/N ratio, supply of basic nutrients in the soil). Plots were established onto which blue lupine (*Lupinus angustifolius* L.), white lupine (*Lupinus alba* L.) and garden lupine (*Lupinus polyphyllus* Lindl) were sown and the studied woody species were planted. Main conclusions from the evaluation of the experiment after five years were as follows:

- Biological amelioration with lupine positively affected the growth parameters (height, increment, root collar diameter) of planted spruce trees.
- Lupine suppressed or even eliminated significantly the symptoms of chlorosis in Norway spruce as compared with the control.
- Biological amelioration with lupine positively affected the spruce nutrition (statistically significant increase of N content in one-year needles, decrease of the luxurious Mg nutrition and increase of K and P contents to optimal threshold level).
- Repeated sowing of lupine for the period of 5 years neither essentially increased the content of humus nor supported the development of humus forms; nevertheless, it enhanced the humus quality (decreased C/N ratio).
- Biological amelioration with lupine increased the content of total nitrogen in the soil.
- Lupine can be sown by manual spreading. Differences in the emergence rate of seeds of all lupines between sowing into the pre-treated soil and manual spreading onto the soil surface ranged within 10–16%.

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