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RESTORATION OF FOREST SOILS AFTER BULLDOZER SITE PREPARATION IN THE ORE MOUNTAINS OVER 20 YEARS DEVELOPMENT

VILÉM PODRÁZSKÝ[1], ALEŠ KAPIČKA[2], MARTIN KOUBA[1]

[1] Department of Silviculture, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Kamýcká 129, 165 21 Praha 6 – Suchdol, Czech Republic; e-mail: podrazsky@lf.czu.cz
[2] Geophysical Institute, Academy of Sciences CR, Boční II, 141 31 Prague 4, Czech Republic; e-mail: kapicka@ig.cas.cz

Abstract

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As a consequence of immission calamity, large deforested areas had to be reforested in the Ore Mountains, on more then 30,000 ha. On almost 4,400 ha of the forest area, the bulldozer site preparation was used, applying heavy machinery at plot preparation, planting and care for new plantations. Removal of the surface humus represented, in respective site conditions, lethal site devastation and has prevented successful growth and development of tree plantings due to the key role of the humus forms. Restoration of the humus form compartment of the forest ecosystem represents the dominant factor in the revitalisation of functioning forest ecosystems in the area of interest. This presented paper documents the results of 20-years of development of forest soil on a bulldozed plot, where blue (Colorado) spruce (*Picea pungens*) was planted and birch (*Betula verrucosa*) was sown. The experiment was established in 1984. The study plot is located on the flat top part of the mountain range, at an altitude of 860 m a.s.l.; bedrock is formed by acid metamorphites (micaschist), and soil type is represented by Cryptopodzols – Podzols. Results confirmed a favourable role of the birch in the new humus form accumulation, and its chemical characteristics (pH, soil adsorption complex, nutrient content and amount). Also the dynamics of heavy metals and trace elements showed the remarkable effects of the humus layer accumulation and transformation.

Key words: immission areas, soil degradation, preparatory species, substitute species, forest soil, soil amelioration, biological amelioration, trace elements

Introduction

Regeneration of the forest stands in the Ore Mountains was typical with the use of heavy machinery and the large use of mechanized treatments. It has been a region with the highest impact of the air pollution calamity in the Czech Republic, even in the so called Black

Triangle industrial region between Czech Republic, Poland and Germany. The restoration of functioning forest ecosystems is a long-term and complex task for Czech forestry (Slodičák, 2008). The reforested area covers roughly 30,000 ha, on 4,400 ha the so called “bulldozer site preparation” was used. The surface layers, including the majority of the surface humus, were removed into windrows, the plots between were planted with different site preparatory species and the birch was sown on many localities including windrow bodies (Ulbrichová, Podrázský, 2003).

Since the early 1980s, some problems were documented in the growth and development of plantings (Jirgle, 1983, 1984). The removal of holorganic horizons was the main cause of heavy soil degradation (Podrázský et al., 2001; Vavříček, Šimková, 2004). Preparatory, or substitute tree species represent an important factor in a remediation strategy of anthropogenically degraded soils. Their role is considered indispensable in the immission areas, where they should temporarily replace target, climax, or commercial species and prepare sites for their reintroduction. Among the species studied, birch (*Betula verrucosa, syn. alba, pendula*) and blue (Colorado) spruce (*Picea pungens*) have the key position. The aim of this study is to document their effect on forest soil development on a typical plot degraded by bulldozer site preparation after 20years of development. Results of this research can be generalised to broader areas of this immission region, as well as other areas under air pollution effects.

Methods

The experimental area is located close to the village of Boleboř, in the Krušné hory (Ore) Mountains The study plot is located on the flat top part. Its altitude is 860 m a.s.l., bedrock is formed by acid metamorphites (micaschist), soil type represents Cryptopodzol, original humus for was typical mor (e.g. Podrázský, 2008), and the forest type group is 7K4 at present. The study area is composed of several parts. The first one was bulldozed up to the A horizon and planted with the blue (Colorado) spruce (*Picea pungens*). On the second sub-part, a birch *Betula verrucosa (*syn. *alba, pendula)* became the dominant tree species, being systematically eliminated on the first one. Soils were studied in the area between windrows, formed by newly accumulated material. Sites were limed several times by forest practice: at the time of establishment (Remeš, Podrázský, 2003) and a few times later. The last aerial limestone application was in 2002. We can calculate 3–4 applications of 2–4 $t.ha^{-1}$ of limestone/calcareous dolomite in the period 1984–2002. Despite detailed study of the experimental plots, practice evidence is missing.

Soil sampling took place in two sites: under blue spruce, which was compared to the birch – both on 1984 bulldozed sites. In each case, sampling was made in 4 replications from particular humus (L, F, H – if possible to distinguish – Green et al., 1993) and mineral soil layers (horizons – Ah). Humus layers of similar character (L + F_1, F_2 + H) were put together when there was not material enough for an individual analysis, or separation was impossible. Bulk samples were formed in the field from material of the same horizons. Holorganic layers were sampled quantitatively, using 25x25 cm steel frames.

Sampling took place in 3 periods: autumn 1994, 1999, and 2004. Standard analytical methods were used for soil analyses: dry matter amount (105 °C) for the holorganic layers, pH, soil adsorption characteristics by Kappen, exchangeable acidity, total humus and nitrogen content by the combustion and Kjeldahl methods, and plant available nutrients in citric acid solution. Standard and verified methods for the determination of the total trace elements contents were also used for the analyses (Podrázský, 2001). Atomic absorption spectrometry was used to determine Pb, Cd, Co, Cr, Cu (graphite furnace AAS) and Zn, Mn, Fe (flame AAS).

Statistical analysis was not possible due to the bulk character of samples in the majority of cases. Results have had a very informative and preliminary character, also representing very well the conditions on the other sites of similar management.

Results and discussion

The dynamics of the surface humus layer restoration is documented in Table 1. In the first period (1984–1994), the dominance of grasses on the blue spruce plot led to a higher accumulation of surface organic matter on the respective subplot. In the following years, the birch accumulated considerably more litter after stand closing and vital growth, connected with a much higher biomass production (Moravčík, Moravčíková, 1994). By contrast, the

T a b l e 1. Comparison of soil characteristics in the stand of blue spruce and birch – dry matter of holorganic layers and soil reaction.

Stand	**Dry mass**			**pH H_2O**			**pH KCl**		
Horizon	**t.ha^{-1}**								
Spruce	**1994**	**1999**	**2004**	**1994**	**1999**	**2004**	**1994**	**1999**	**2004**
L + F1	2.01		5.25	5.63		5.90	4.88		5.30
F2	3.10			6.11			5.55		
H	4.95	14.52	13.80	5.45	6.60	6.40	4.74	4.00	5.80
Sum	**10.04**	**14.52**	**19.05**						
Ah				5.34	5.40	4.70	4.13	3.50	3.90
Birch									
L + F1	1.45	4.72	6.12	5.03	5.80	5.50	4.62	4.20	5.30
F2	2.11			5.21			4.32		
H	4.34	9.00	18.69	5.78	5.60	4.80	5.24	3.90	4.50
Sum	**8.02**	**13.72**	**24.81**						
Ah				6.25	5.50	5.10	5.43	3.40	4.10

T a b l e 2. Comparison of soil adsorption complex characteristics in the stand of blue spruce and birch.

Stand	**S**			**H**			**T**			**V**		
Horizon	**mekv/100 g**									**%**		
Spruce	**1994**	**1999**	**2004**	**1994**	**1999**	**2004**	**1994**	**1999**	**2004**	**1994**	**1999**	**2004**
L + F1	94.0	--	47.7	11.6		10.0	44.7		57.7	73.9		82.7
F2	33.0	--		5.6			40.7			86.3		
H	35.2	14.3	46.1	7.3	20.0	4.5	27.2	34.4	50.6	73.3	41.7	90.0
Ah	4.0	6.4	4.6	17.4	9.5	7.7	21.5	15.9	12.3	19.0	40.2	37.3
Birch												
L + F1	35.1	35.4	59.9	17.5	30.3	17.9	52.6	65.7	77.9	66.7	53.8	77.0
F2	23.4			13.3			36.7			63.7		
H	63.0	26.5	38.6	18.6	21.9	19.1	81.6	48.4	57.8	77.2	54.7	66.9
Ah	39.9	3.6	10.2	9.1	8.9	7.8	48.0	12.4	18.0	11.0	28.7	57.2

herb (grass) vegetation has been dominant in this process in the spruce stand through recent years. These tendencies resulted in the accumulation of surface humus in the amount of 19.05 $t.ha^{-1}$ in the blue spruce stand, compared wit 24.81 $t.ha^{-1}$ in the birch stand in 2004. Very similar results were documented in neighbouring localities (Podrázský, 2008) or in other regions (Moravčík, Podrázský, 1993). All sources confirm the blue spruce as the minor species for humus quantity, as well as for quality formation.

The differing effects of both species are reflected by the soil reactions. The grass vegetation in the spruce stand produced a litter of higher pH in comparison with the birch. Moreover, the practice liming functioned more effectively in the spruce stand, having the character of an open area with thinner surface humus for a much longer time. The stand has been closing only in the last years, and not yet fully. The liming was conducted several times during the experiment duration, the last time being in 2002 using ground machinery sooner (aerially, the last time). These factors contributed to higher values of the pH in the upper holorganic horizons in the spruce stand. The better effect of the birch on litter formation and transformation – on the contrary – resulted in more favourable values of soil pH in the Ah horizons there. This again corresponds with other experiments (Kantor, 1989; Podrázský, 2008; Remeš, Podrázský, 2003).

The state of the soil adsorption complex characteristics (S – base content, H – hydrolytical acidity, T – cation exchange capacity, V – base saturation) reflects all of the above mentioned factors (Table 2). The grass litter influenced favourably the uppermost holorganic layers in the blue spruce stand; the functioning of the birch litter transformation prevailed in the lower. The bases content was more favourable in the birch stand, especially in the mineral horizon. There was a much higher humus content (15.8% in contrast to 6.9%) in the Ah horizon in 1994; it contributed to a substantially larger S value in this horizon under birch. The sampling effect played a role in the next sampling terms probably due to the high variability of soil horizon characteristics.

The same fact resulted in the higher value of hydrolytical acidity and cation exchange capacity there, and to the lower base saturation as well. These soil characteristics are closely related to the organic matter content. The thinner layer of the surface humus in the spruce stand has – as a consequence – also more visible effects of the practice liming, resulting in higher base saturation in the upper horizons. In general, the birch litter effects prevail in the H and Ah horizons, reflected by the higher cation exchange capacity and base saturation.

Also the plant available contents show visible differences (Table 3). The plant available phosphorus content is reflected in the L + F1 layer effects of biological pollution, or possibly as a result of a laboratory error in 2004 – as the value deviates by two orders (bold figure). In lower horizons, values are visibly more favourable in the birch stand. A similar trend of higher content of plant available potassium was analyzed for birch, documenting a more efficient recycling of this nutrient and a higher quality of the birch litter.

Values of plant available calcium reflect a lower buffering effect of the humus form in the blue spruce stand. In 1994, the effects of older liming were visible in lower horizons there, while higher effects of the new liming (2002) were visible in the upper horizons. A similar tendency was documented for plant available magnesium contents. Contents of iron in the

T a b l e 3. Comparison of plant available nutrient contents in the stand of blue spruce and birch.

Stand	P_2O_5		K_2O		CaO		MgO		Fe_2O_5	
Horizon	**mg/kg**									
Spruce	**1999**	**2004**	**1999**	**2004**	**1999**	**2004**	**1999**	**2004**	**1999**	**2004**
L + F1		27		640		10,720		3,733		1,283
F2										
H	169	138	713	307	2133	13,800	149	5,640	1,504	1,986
Ah	131	149	102	87	1,100	800	47	418	2,986	2,391
Birch										
L + F1	733	**2,045**	1,153	1,680	4,800	11,680	733	1,691	264	104
F2										
H	389	359	673	760	2,800	7,120	335	1,452	343	1,091
Ah	125	168	105	98	513	1603	43	178	1,006	1,876

citric acid soluble form indicate more pronounced acidification and aggressive conditions in the soil under blue spruce as well, and they do not correlate with the base contents.

The total nitrogen contents (Table 4) and amount fixed within holorganic layers (Table 5) show a much more effective nitrogen fixation potential and dynamics in the birch stand, as well as a higher birch litter quality. The same trend is visible for the total phosphorus content and fixed quantity. The opposite situation is documented in the case of total potassium – due to a higher K-content of grass litter (Klimo, 1994). This had no effect on the plant available content of this nutrient in the plant available form (Table 3), being higher in the humus form of the birch stand.

A similar deviation was documented for total calcium and magnesium contents. The practice liming obviously influenced the total nutrient contents in the form of fine particles of dolomitic limestone in particular layers. Thinner surface humus in the blue spruce stand probably conserved more fine particles, thus helping the solution throughout the total nutrient form analyses. These particles are not as numerous in the birch stand, probably

T a b l e 4. Total nutrient contents in the holorganic horizons of stand of blue spruce and birch.

Stand	N			P			K			Ca			Mg		
Horizon	**%**														
Spruce	**1994**	**1999**	**2004**	**1994**	**1999**	**2004**	**1994**	**1999**	**2004**	**1994**	**1999**	**2004**	**1994**	**1999**	**2004**
L + F1	0.84		1.19	0.103		0.148	0.673		0.580	0.710		0.340	0.100		0.428
F2	0.86			0.074			0.766			0.640			0.107		
H	0.85	0.74	0.74	0.067	0.070	0.104	0.805	0.420	0.590	0.320	0.120	1.820	0.075	0.024	1.249
Birch															
L + F1	1.43		2.16	0.132	0.100	0.196	0.510	0.240	0.280	0.840	0.240	1.020	0.091	0.024	0.200
F2	1.59	1.87		0.145			0.418			0.400			0.096		
H	0.94	1.34	1.41	0.087	0.080	0.128	0.310	0.280	0.490	0.860	0.140	0.140	0.132	0.020	0.200

T a b l e 5. Total nutrient amount in the holorganic horizons of stand of blue spruce and birch.

Stand	**N**			**P**			**K**			**Ca**			**Mg**		
Horizon	**kg/ha**														
Spruce	**1994**	**1999**	**2004**	**1994**	**1999**	**2004**	**1994**	**1999**	**2004**	**1994**	**1999**	**2004**	**1994**	**1999**	**2004**
L + F1	17		62	2.1		7.8	13.5		30.4	14.3		17.8	2.0		22.5
F2	27			2.3			23.7			19.8			3.3		
H	42	107	102	3.3	10.2	14.4	39.8	61.0	81.4	15.8	17.4	251.2	3.7	3.5	172.4
Total	**86**	**107**	**164**	**7.7**	**10.2**	**22.2**	**77.0**	**61.0**	**111.8**	**49.9**	**17.4**	**269.0**	**9.0**	**3.5**	**194.9**
Birch															
L + F1	21		132	1.9		12.0	7.4		17.1	12.2		62.4	1.3		12.2
F2	34	144		3.1	4.7		8.8	11.3		8.4	11.3		2.0	1.1	
H	41	121	263	3.8	7.2	23.9	13.5	25.2	91.6	37.3	12.6	26.2	5.7	1.8	37.4
Total	**96**	**265**	**395**	**8.8**	**11.9**	**35.9**	**29.7**	**36.5**	**108.7**	**57.9**	**23.9**	**88.6**	**9.0**	**2.9**	**49.6**

being sooner dissolved and converted into other forms, including biomass. The dilution effect is also possible.

The total carbon amount fixed in the holorganic layers shows more than double the value in the birch stand (Table 6). This directly corresponds with the surface humus necromass and faster development of humus forms under the birch. Also the N-Kjeldahl contents are higher in the birch stand and consequently the C/N ratio is very comparable in both stands, being slightly lower in the birch. The values are in general under 20, so the danger of excessive N-mineralisation and losses, e.g. as a result of continuing liming, is topical. Also the pH and V values do not correspond to the typical forest site in higher elevation, and eventual further chemical soil amelioration

T a b l e 6. Amount of fixed total carbon, eldahl nitrogen content and C/N ratio in the stand of blue spruce and birch.

Stand	**Total carbon**				**Nitrogen - Kjeldahl**		**C/N**	
Horizon	**kg.ha^{-1}**		**%**					
Spruce	**1999**	**2004**	**1999**	**2004**	**1999**	**2004**	**1999**	**2004**
L + F1		1,019		19.41		1.04		19
F2								
H	1,861	1,391	12.82	10.08	0.7	0.66	18	15
Sum	**1,861**	**2,410**						
Ah			5.10	3.83	0.22	0.18	23	21
Birch								
L + F1		1,964		32.09		2.08		15
F2	2,097		44.43		1.93		23	
H	2,908	4,400	32.31	23.54	1.56	1.42	21	17
Sum	**5,005**	**6,364**						
Ah			4.12	4.52	0.23	0.25	18	18

represents an environmental risk. Only the correction of tree nutrition discrepancies represents corresponding treatment. Further soil property changes are not desirable any more.

Considerable attention is paid to heavy metals and risk elements in particular monitoring programmes, among the most important are Forest Focus (formerly ICP Forests – Uhlířová et al., 1998) and the programme of ÚKZÚZ (Fiala et al., 2008). This topic is described also in many presentations (Barszcz, Malek 2008; Novotný et al., 2008). On the other hand, these elements are important micronutrients in some cases and their deficit can occur (Bergmann, 1988). Bioelements as well as load substances show distinct dynamics in forest ecosystems. They are trans-located, accumulated and can undergo chemical changes and transformations. Common analyses register their contents in bulk humus samples, particular mineral soil horizons, vegetation, and surface and ground water, not distinguishing considerable dynamics in the humus form. Our analyses enable us to describe this process.

The total Fe-content obviously shows geogenic behaviour – its contents increase with the increasing depth of the particular horizons; it is similar with the As contents. By contrast, Cd, and to large extent also Co, exhibits an atmogenic origin. Their contents are the highest in the upper holorganic horizons. Lead content usually increases with the depth of horizon; in the transition H – Ah; it stays stable in the birch stand. Chromium (Cr) contents are homogenous throughout the humus form horizons in the spruce stand, showing accumulation with the holorganic layers transformation in the birch, which is more developed. It can be accumulated in humus layers due to vegetation development and biological activity. The same trend can be supposed for zinc (Zn), an important micronutrient, often deficient in immission areas. Its dynamics can be the result of bioaccumulation.

Similar dynamics are also typical for macronutrients, but especially in intact soils. In our case, nitrogen (also P, Ca, Mg) showed bioaccumulation in horizons with the highest activity (1994). The mixing of horizons, bulldozing, and heavy liming in 2002, hid these dynamics, which are otherwise visible in other cases (Remeš, Podrázský, 2006; Thietema, 1992; Wesemael, 1992).

T a b l e 7. Content of micro- and risk elements in the surface ecosystem compartments in the stand of blue spruce and birch on the Boleboř locality (mg/kg – 1999).

Plot	Horizon	Fe	Zn	Pb	Cr	Co	Cd	As
Spruce	**Herbs**	1840	71	27.6	4.52	0.26	0.28	0.63
	L+F+H	5430	23	57.4	4.67	0.51	0.21	1.15
	Ah	8200	5	62.3	4.86	0.44	0.08	1.06
Birch	**Herbs**	120	100	9.5	0.53	0.14	0.18	0.08
	L+F	700	137	31.7	0.87	0.39	0.54	0.29
	H	1830	90	49.4	2.78	0.31	0.35	0.63
	Ah	2620	5.4	44.6	1.47	0.17	0.05	0.90

Conclusion

Bulldozing represents a heavy impact on a forest soil. Its recovery can be anticipated in the scale of decades, even centuries. During the first 20 years, 19 to 25 t/ha of newly formed holorganic horizons were documented, compared with the cca 150–200 t/ha on intact sites. Thus, birch seems to be more effective compared to stagnating blue spruce, where grass litter is still dominant.

By contrast, a thinner surface humus of blue spruce (with effective grass) stand buffers the liming effects less and better conserves the fine particles immediately affecting the surface layers. This results in higher pH, base saturation (V-value), as well as bivalent base (Ca, Mg) contents and amounts in holorganic layers there.

Nitrogen, along with phosphorus dynamics and recycling, seems to be better in the birch stand. In the first two decades, birch restored the site more effectively.

The heavy metals exhibited differentiated dynamics in the humus layer profile. Not only were the processes including vegetation and bulk soil of ecological importance, but also within the holorganic layers, we could detect important ecological processes. Total Fe and As showed visible effects of the mineral soil, and the Pb, Cd and Co contents indicated effects of air pollution.

Twenty years of research has shown considerable potential for studied sites to be restored within a century. On the other hand, the potential risk of non-favourable management of nutrient and organic matter cycles is also indicated. The use of effects of the preparatory species and re-introduction of klimax species should be the next quick step. The study of element cycles will also help formulate proper site management in the future.

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