Silvicultural assessment of reforestation under specific spoil bank conditions

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ABSTRACT: Forest reclamation of spoil banks in mining areas in the North-West of the country started in the second half of the last century. Nowadays forest stands growing on anthropogenic substrates which are still unlike to forest soils, are getting in the phase of possible natural and/or artificial regeneration. The basic characteristics of substrate in the area and ecological attitude of used tree species are driving variables for successful regenerations. The study summarizes the vitality and growth of selected species on anthropogenic substrates in the area with the recommendations of key tree species used for forest reclamation. The results show the best adaptation to anthropogenic substrates for black alder and maple.

Keywords: forest reclamation; afforestation of spoil banks; anthropogenic substrates; growth; vitality; black alder; Norway maple; English oak; rowan tree; European ash; linden

The actual structure and species composition of forest stands on spoil banks in the Sokolov brown coal mining area are a result of forest reclamations which started in the forties of the last century. The species composition is broadly diversified creating thousands of hectares of forest reclamations and could be used as a good knowledge database for future forest regeneration and afforestation of spoil banks in mining areas.

Research and evaluation of the results have been conducted on the basic system of research plots from different aspects for more than forty years and that is why the data have a general meaning for the given subject. Important aspects of this research are relationships between anthropogenic substrates of spoil banks and the growth, structure and species composition of stands of which some are now forty years old. The results could serve as a basis for guidance of forest reclamation in the areas heavily influenced by mining and industrial loads and air emissions.

Pedological features (soil physics and chemistry as well as hydropedology) together with climatic conditions on spoil banks are principal limits for forest reclamation and/or forest regeneration (Dimitrovský 1989). The uniqueness of anthropogenic substrates could be described as follows:

- pedogenesis is in initial phases,
- specific weight is not regular throughout the profile,
- high incidence of macropores of different forms and shapes,
- non-regular humidity throughout the profile,
- desaggregation processes are irregular.

The structure and texture of anthropogenic substrates are principal limits for the growth of forest stands as well as their regeneration and/or afforestation. The most important attributes of anthropogenic substrates influencing regeneration on spoil banks are:

- geological and petrographical structure of upper layers on spoil banks and particularly their mineral composition,
- soil chemistry and particularly the availability of macrobiotic elements,
- soil physics (desaggregation processes influence the volume of pores, their structure and texture),
- hydropedology (water content, infiltration potential of different upper layers on spoil banks),

– ecological potential of tree species and their ecotypes.

Weathering processes influencing the nutrition quality of protopedological and mesopedological profiles as the ultimate condition for the choice of used species are among the most important limits for afforestation and regeneration of forests on spoil banks (Dimitrovský 1999). The performance of naturally regenerated seedlings is mostly evaluated on forest soils (e.g. Holgén, Hanell 2000), but not on substrates of spoil banks. Afforestation on difficult and very specific sites is very often supported by the improvement of root environment. Fertilization is one of the most common practices (e.g. Kupka 2003, 2005, 2006). The application of auxinoids (Bártová, Mauer 2005) or hydro-absorbents (Puhlová, Šmelková 1998) to the root system was tested in different species but again not in specific anthropogenic substrates.

Forest reclamation creates forest stands on spoil banks bringing all environmental services to the countryside and their inhabitants as well as starting amelioration processes in anthropogenic substrates.

Amelioration effects are among the most important goals in forest reclamation. These effects were often studied (e.g. Kantor 1989) but again not on spoil banks. Species used for forest reclamation could be damaged by wet snow (Kula, Kawulok 1998) and these aspects should also be taken into account.

Black alder (*Alnus glutinosa*), Norway maple (*Acer platanoides*), English oak (*Quercus robur*), rowan tree (*Sorbus aucuparia*), European ash (*Fraxinus excelsior*) and linden (*Tilia cordata*) were chosen as reference tree species.

The aim of the study was to evaluate the height growth of selected species in the first years after their planting and to assess their potential to create close stands which are able to bring all above-mentioned benefits.

METHODS AND DATA

Anthropogenic substrates can be divided into two main groups according to the time of their formation: (*i*) tertiary period when about 90% of actual anthropogenic substrates in the study area were created and (*ii*) quaternary period when only about 10% were formed in the Sokolov mining area. The geological and petrographical structure strongly influences the prime character of upper layers and poses limits for the tree species that can be planted. The content of nutrient supply is changing in time and depends on desaggregation processes and hydropedological changes in the whole profile. Basic evaluations of

Table 1. Quality and mortality of seedlings

Code	1	2	3	4	5
Description	vital tree with normal stem and crown structure	vital tree with small damage to crown or stem	vital tree with significantly damaged stem and/or crown	tree with low vitality (dying tree)	(freshly) dead tree

Table 2. Emission data in the area concerned for the last ten years

Year	Volume of burned coal in the area (mill t)	SO_2 (ths t)	NO_x (ths t)	Solid particles (ths t)
1993	2.45	20.1	8.2	1.7
1994	2.34	16.1	6.6	1.8
1995	2.17	13.0	2.4	1.5
1996	2.78	14.9	8.3	1.3
1997	2.72	12.7	8.8	1.0
1998	2.86	11.5	5.6	0.8
1999	2.88	11.4	4.6	0.6
2000	3.15	12.7	5.2	0.5
2001	3.12	12.9	5.0	0.5
2002	3.18	10.0	5.0	0.4
2003	3.40	8.1	5.0	0.5
2004	3.44	9.0	5.3	0.3

Table 3. Content and availability of potassium according to the degree of efflorescence

Spoil bank area	Anthropogenic substrate condition	Content of K_2O (%)		Available potassium
		total	extract in 20% HCl	(mg/kg)
Velký Riesel[1]	effloresced	0.81	0.73	59
	non-effloresced	1.80	0.48	–
Dukla[1]	effloresced	1.35	0.82	60
	non-effloresced	0.73	0.64	64
Bohemia[2]	effloresced	1.60	0.65	69
	non-effloresced	0.69	0.63	78
Vilém[2]	effloresced	2.82	0.63	53
	non-effloresced	1.95	0.57	60

[1] Forest reclamation started in 1962, [2] forest reclamation started in 1934

pedological data use standard methods taking into account specific conditions in the structure of particular anthropogenic substrates and their physical and chemical characteristics (Dimitrovský 2001).

The climatic conditions are characterized by an average annual temperature of 7.3°C and average annual precipitation of 511 mm, which means a moderately warm and moderately dry zone.

All plants on research plots were bare-root seedlings two years old, only linden and maple were plants of the same age. The planting was realized in spring 1999 using the hole system of planting with the hole size of 35 cm by 35 cm.

Research plots with three replications were founded in young plantations to assess the "second generation" of forest reclamation. The plots of square shape 10 by 10 m are randomly located in the plantation avoiding the 5-m wide edge belt of the stand. About 100 trees were planted per research plot at the beginning. Trees damaged by biotic and/or abiotic agents were not included in the next assessment of height increment to avoid the misrepresentation of data.

Dendrometric characteristics of tree species on research plots were regularly taken at the end of vegetation period. Heights of plants were measured with a measuring stick to the nearest 1 cm. Quality data covering the architecture of stem and branches including mortality were recorded as well. The quality evaluation was codified as shown in Table 1.

The average codes for the quality and mortality of species were calculated every year as an average of all trees (but only fresh dead trees included) on research plots.

RESULTS AND DISCUSSION

The variance of nutrient availability on different spoil banks is very large. The chemical conditions of anthropogenic substrates influencing sorption, clay volume and supply of Ca, Mg, P and K in the profile are given in Tables 3 to 5. The ongoing changes are rather slow as it could be proved at Antonin spoil bank, which had chemical reaction pH (KCl) 6.7–7.4 in 1969 and pH (KCl) has changed into the range of 6.2–7.1 only until

Table 4. The variation of CaO in anthropogenic substrates according to the degree of efflorescence

Spoil bank area	Anthropogenic substrate condition	Content of CaO (%)		Extract in 1% of citric acid
		total	extract in 20% HCl	(mg/kg)
Velký Riesel[1]	effloresced	1.14	0.89	4,119
	non-effloresced	1.30	0.92	3,846
Dukla[1]	effloresced	1.63	1.17	5,832
	non-effloresced	1.50	0.76	5,160
Bohemia[2]	effloresced	1.02	0.76	3,813
	non-effloresced	0.96	0.66	3,463
Vilém[2]	effloresced	2.00	1.34	7,324
	non-effloresced	2.36	1.67	8,439

[1] Forest reclamation started in 1962, [2] forest reclamation started in 1934

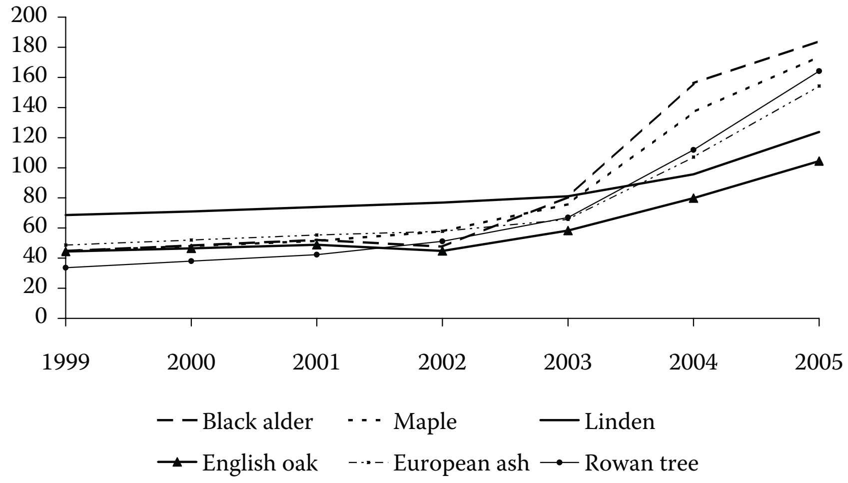

Fig. 1. Height growth of planted two-years-old seedlings (linden and maple were plants of the same age)

now. The situation in the chemical reaction is somehow contradictory to the heavy air pollution impact on forest soils in the seventies and eighties when acidification took place in forests. The emission situation from the year 1993 is described in Table 2.

In spite of the emission situation described in Table 2 the pH (KCl) reaction of substrates in the research area has diminished from 6.7 to 6.4 only in the last 20 years.

The characteristics of anthropogenic substrate condition and nutrient availability are given in the following tables. Table 3 describes the content and availability of potassium according to the degree of efflorescence while Table 4 shows the variation of CaO in percent in anthropogenic substrates and Table 5 gives the details on availability of phosphorus and magnesium.

The variation is strongly influenced by the time span of amelioration impacts of stands established on spoil banks. The oldest forest stands were established in 1934 in the area of spoil banks Vilém and Bohemia while the first two areas Velký Riesel and Dukla are younger with forest reclamation starting in 1962.

All research plots confirm the finding that the driving variables for successful species composition are initial chemical reaction and infiltration capacity. The physical structure, type and proportion of pores fundamentally restrict the root system depth of forest stands on anthropogenic substrates and influence the long-term stability of forest stands on spoil banks.

Height growth is one of the main features of the species in terms of their suitability for forest reclamation (Dimitrovský 1999). The others are low mortality, their amelioration potential for anthropogenic substrates, tolerance to emissions, etc. The basic results are given in Fig. 1.

Table 5. The variation of MgO and P_2O_5 in anthropogenic substrates according to the degree of efflorescence

Spoil bank area	Anthropogenic substrate condition	Content of MgO (%)		Content of P_2O_5 (%) total	Available phosphorus (mg/kg)
		total	extract in 20% HCl		
Velký Riesel[1]	effloresced	1.73	1.30	0.38	2.5
	non-effloresced	3.04	2.03	0.27	2.0
Dukla[1]	effloresced	1.61	1.10	0.41	2.5
	non-effloresced	2.20	1.71	0.32	2.0
Bohemia[2]	effloresced	1.26	0.97	0.29	3.5
	non-effloresced	1.76	1.45	0.27	2.5
Vilém[2]	effloresced	1.93	1.48	0.38	2.0
	non-effloresced	3.16	2.36	0.31	–

[1] Forest reclamation started in 1962, [2] forest reclamation started in 1934

Table 6. The quality of plants during 7 years after planting

	1999	2000	2001	2002	2003	2004	2005	Average
Black alder	1.90	2.25	1.95	2.10	2.05	1.95	2.20	2.05
Maple	2.15	2.10	2.25	2.20	2.20	2.10	2.05	2.15
Linden	2.75	3.00	3.10	2.85	2.20	2.10	2.05	2.60
English oak	2.90	3.10	2.85	2.95	2.45	2.80	2.85	2.85
European ash	3.30	3.20	3.35	2.85	2.90	3.00	3.10	3.10
Rowan tree								3.20

There were not any significant differences in height except the linden in the year of planting. Following the recovering phase after planting which lasted till the year 2002 broadly three groups of species could be recognized. The first group with accelerated growth where the total average height increased more than four times compared to the original height within six years is composed of black alder and maple. In the second group including rowan tree and European ash it increased about three times compared to the original height. The last group of the slowest growing species contains English oak and linden. The differences between the above given groups were statistically significant on the usual level of significance.

The quality together with mortality is given in Table 6. The results show the best adaptation to anthropogenic substrates in black alder and maple, while rowan tree (frequently damaged by game) and European ash are the worst. The results agree with the data published by Dimitrovský (1999), who reported alder, maple, and poplars as the best tree species for spoil banks.

Mortality together with damage to the stem and/or terminal part was mostly pronounced in the second and sometimes in the third year after planting. There were no large fluctuations in quality during the whole period between different species, i.e. the good quality was kept all the time and vice versa.

CONCLUSIONS

The structure and species composition of forest stands on spoil banks in the brown coal mining area Sokolov are a result of forest reclamation which started in the forties of the last century. The actual species composition is diversified.

Research has been conducted from different aspects on the basic system of research plots for more than forty years in this area. Important aspects of the research are relationships between anthropogenic substrates of spoil banks and the growth, structure and species composition of stands some of which are forty years old now. The results could serve as a basis for guidance of forest reclamation in the areas heavily influenced by mining and industrial loads and air emissions. Pedological features (soil physics and chemistry as well as hydropedology) together with climatic conditions on spoil banks are principal limits for forest reclamation and/or forest regeneration. Weathering processes influencing the nutrition quality of protopedological and mesopedological profiles as the ultimate condition for the choice of used species are limits for afforestation and regeneration of forests on spoil banks.

The aim of the study was to evaluate the height growth of selected species in the first years after their planting and to asses their potential to create closed-canopy stands.

The variance of nutrient availability on different spoil banks is very large. The chemical conditions of anthropogenic substrates influencing sorption, clay volume and supply of Ca, Mg, P and K in the profiles are given in Tables 3 to 5. The chemical reaction is somehow contradictory to the heavy air pollution impact on forest soils in the seventies and eighties when acidification was going on in forests. The emission situation from the year 1993 is described in Table 2.

The height growth was investigated on research plots together with mortality and plant quality. There were not any significant differences in height except in linden in the year of planting. Following the recovering phase after planting which lasted till the year 2002 broadly three groups of species could be recognized. The first group with accelerated growth where the total average height exceeded the initial height more than four times within six years comprises black alder and rowan tree. The second group including maple and European ash reached about a triple of the original height. The last group with the slowest growing species contains English oak and linden. The differences between the above groups were statistically significant on the usual level of significance.

The quality together with mortality is given in Table 6. The results show the best adaptation to anthropogenic substrates in black alder and maple, while rowan tree (frequently damaged by game) and European ash are the worst. The results agree with the data published by Dimitrovský (1999), who reported alder, maple, and poplars as the best tree species for spoil banks.

Therefore the species of the first and second group are recommended for forest reclamations on these types of anthropogenic substrates in the area concerned.

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Received for publication March 28, 2006
Accepted after corrections May 11, 2006

Pěstební zhodnocení lesních kultur ve specifických podmínkách výsypek

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ABSTRAKT: Lesnické rekultivace výsypek v severozápadních Čechách probíhají už od poloviny minulého století. Lesní porosty na těchto výsypkách, které stále nemají charakter „normálních“ lesních půd, se někdy dostávají do fáze, kdy je nutná či možná umělá či přirozená obnova. Rozhodujícími činiteli v tomto procesu jsou vlastnosti těchto substrátů a ekologické požadavky vysazovaných dřevin. Studie shrnuje vitalitu a výškový růst některých vybraných dřevin. Na základě dosavadních výsledků lze jako nejvhodnější dřeviny doporučit olši lepkavou a javor mléč.

Klíčová slova: lesnická rekultivace; zalesnění výsypek; antropogenní substráty; růst; vitalita; olše lepkavá; javor mléč; dub letní; jeřáb ptačí; jasan ztepilý; lípa

Druhové složení a struktura porostů na výsypkách na Sokolovsku je výsledkem lesnických rekultivací, které se začaly realizovat už ve druhé polovině minulého století. Hned také začal výzkum na těchto plochách, aby získané výsledky mohly být zobecněny pro další úspěšné rekultivace. Antropogenní substráty výsypek jsou totiž velmi specifické a jejich pedologické i hydropedologické vlastnosti jsou velmi odlišné od těch, které jsou na normálních lesních půdách. Z těchto zvláštností je třeba zdůraznit zejména:

– pedogeneze je v iniciální fázi,
– nerovnoměrnost objemové hmotnosti,
– nadměrný výskyt mokropórů různých tvarů a velikostí,
– nerovnoměrnou vlhkost v celém profilu,
– velmi rozdílnou intenzitu zvětrávání (desagregace).

Lesnická rekultivace nejen urychluje pedogenezi antropogenních substrátů, ale existence lesních porostů také přináší všechny pozitivní mimoprodukční funkce lesa do krajiny silně devastované povrchovou těžbou.

Cílem příspěvku je ohodnocení vybraných dřevin použitých ke znovuzalesnění výsypek v oblasti Sokolova z hlediska jejich vitality a výškového růstu pro lesnické rekultivace.

Výsypky Sokolovska jsou tvořeny převážně substráty terciérního stáří (asi 90 %) a kvartérního stáří (asi 10 %). Klimatické podmínky jsou mírně teplé a mírně suché s průměrnou roční teplotou 7,3 °C a s ročním úhrnem srážek 511 mm.

Výzkumné plochy byla založeny v novém zalesnění jako arové čtvercové plochy se třemi opakováními; přitom byl vynechán 5 m široký okraj nově založeného porostu. Vedle dendrometrických měření bylo prováděno i jednoduché hodnocení kvality mladých stromků. Výsadba byla provedena dvouletými prostokořennými semenáčky či sazenicemi (jen javor a lípa byly školkované dvouleté sazenice).

Jednou ze specifik antropogenních substrátů je skutečnost, že přes vysokou imisní zátěž (tab. 1) je jejich chemická reakce neutrální až mírně zásaditá a tato hodnota je poměrně stálá. Podrobnější charakteristiky pedologických vlastností substrátů na jednotlivých výsypkách podávají tab. 3 až 5.

Výškový vývoj stromků po jejich výsadbě je zřejmý z obr. 1. Ze sledovaných dřevin lze vytvořit tři skupiny, které se vzájemně výrazně liší svou dynamikou růstu. První skupinu tvoří olše lepkavá a javor, které prokazují nejvyšší dynamiku růstu, zatímco nejhorší jsou v tomto směru lípa a dub letní. Z hlediska kvality a mortality se jako nejlepší prokázaly olše lepkavá a javor, zatímco nejvíce poškozován byl a zvýšenou mortalitu prokázal jasan ztepilý a jeřáb ptačí. První dvě uvedené dřeviny lze proto doporučit jako nejvhodnější pro lesnické rekultivace na těchto typech antropogenních substrátů.

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