Experiences with forest reclamation of settling basins after industrial processing of manganese ore and pyritic shales

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ABSTRACT: This article describes the problem of forest reclamation of settling basins after industrial processing of manganese ore and pyritic shale at the age of 20–30 years. Soil properties of anthropogenic soil (overlaid layers, deposited sediments), nutrition state of assimilation organs, vitality of aboveground organs of tree species were investigated by instant visual evaluation using recommended macromorphological criteria and architecture of the Scots pine (*Pinus sylvestris* L.) root system.

Keywords: forest reclamation; settling basin; manganese ores; pyritic shales; anthropogenic soil; soil properties; tree species root system; growth vitality; phytotoxicity

In the 1950s a great quarry for the mining of manganese ore and pyritic shales was opened and operated at Chvaletice in order to ensure the production of sulphuric acid in the Czech Republic. Extracted ore was crushed, ground and floated with the main processing aim to obtain a pyritic concentrate. Produced debris was carried away by water and gradually stored in three independent settling basins situated on the plateau between the railroad and the Elbe River. After the year 1962 these settling basins were further extracted by leaching. The stored material is a heterogeneous mixture that consists of two main types of ores that were mined at Chvaletice – pyritic shales and manganese ores. It is evident that the stored material contains other admixtures tied with the construction of roads, dams and reclamations including the storing of another type of debris from surrounding agglomerations. The first and the second settling basin of total volume ca. 22,800,000 m^3 within the area of ca. 76 ha were filled with waste up to the height of ca. 18–26 m above sea level of the adjacent terrain, the third one was used only up to its half. After the finishing of dumping, the basin slopes were adjusted by terracing at a ratio 1:3 and covered by reclaimable soils (sugar scums) of thickness 0.3–0.5 m. The plateau was grassed down (except for the establishment of an experimental plot with Scots pine planting on a small area) and the slopes were afforested at random by deciduous and coniferous tree species. This settling basin is the only source of manganese in the CR territory that can be industrially usable in future (Peták, Fröhlichová 1989).

Based on long-term research experiences the Research Institute for Soil and Water Management (Patejdl, Malý 1969) recommended the overlaying of this depot by reclaimable soils or sugar scums of thickness up to 0.5 cm together with permanent grassing down as the most suitable reclamation variant of its surface improvement. In the late 1970 to 1980 this recommendation was realized only on the plateau, the slopes were mostly afforested by trees and shrubs.

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MATERIAL AND METHOD

Assessment of the present forest state of the reclaimed part of waste depot was done on the basis of this investigation

(1) Determination of soil properties of overlaying layer and deposited waste (Tables 1 to 3).
(2) Determination of leaf analyses of tree species important for reclamation (Table 4).
(3) Determination of important tree species in the territory concerned and frequency of their occurrence (Table 5).
(4) Determination of the vitality of aboveground tree species organs by an instant visual assessment of available macromorphological criteria recommended by some authors (Becker 1987; Roloff 1989; Hartmann et al. 2001; Kolařík 2005; Fér, Alexandr 2006). This assessment comprised the following data concerning diagnostic features with definition of qualitative and quantitative parameters (Table 6):

- foliage degree or defoliation. Defoliation is defined by the proportional volume of total crown habit or its loss with numerical marking 0–4 where 0 is foliage loss of 0–10%, 1 loss in 11–25%, 2 loss 26–60%, 3 loss 61–99% and 4 100% loss or dead (dry) tree;
- small leaves, numerically 0 is for normal leaf, 1 for a leaf to the half of the leaf blade, 2 is for a leaf smaller than a half of the leaf blade of normal leaf;
- colour changes (leaf blade), in the given case the occurrence of chlorosis is presented by sign +;
- malformation of branch structures. Evaluation of broadleaves regards the growth model of shoots (Roloff 1989) that comprises 4 stages (exploration, degeneration, stagnation, resignation);
- crown desiccation where 0 means desiccation not found, 1 is for desiccation of 1 to 2-year old shoots without visible tendency of dynamic distribution of dry branches, 2 marks desiccation of stronger branches mainly within the top crown part, tendency of dynamic crown decline is evident, 3 means that more than 40% of the crown volume is dry, and desiccation continues, 4 represents a mostly dry crown;
- multiple trunks, development of multiple trunks in the tree taxa originally with one trunk (truncus) is marked by +;
- proliferation (thickening) of the basic stem part between the inhibition growth of roots in the space of available rhizosphere and the aboveground part of tree species is marked as +.

The architecture of the formed root system was assessed mainly in Scots pine individuals that are the most damaged by windfalls at present. 24 trees were evaluated while the main attention with regard to the windthrow position (total area of the denuded root system) was paid to the type of formation of skeletal roots that involve horizontal roots and vertical roots – taproot, heart-shaped roots and vertical and oblique anchor roots. The evaluation of the root system is completed by findings obtained by the horizontal exposure of horizontal roots in six trees not damaged by windthrows.

RESULTS AND DISCUSSION

The anthropogenic soil formed on the plateau of settling basins can be estimated as humic to deep-humic, in most cases on slopes changing to overlaid anthropogenic soil (Němeček 2001). The overlaid layer of the slope interrupted by 2–3 anti-erosion banks is formed of reclaimable soil of total thickness 0.3–0.4 m (locally also sugar scums were used, often enhanced skeletonization) that is loamy (it is characterized by favourable hydrophysical properties), mildly or strongly acid, adsorptively unsaturated, with a high content of organic substances as well as with sufficient supplies of all possible nutrients – P, K, Mg, Ca for forestry needs (Neuberg 1990). Unlike the overlaid layer the deposited sediment has some specific properties. According to the grain the waste can be evaluated as loamy-sandy soil with a prevailing proportion of one grain fraction – fine sand (a consequence of previous ore processing), in hydrophysical terms it is a more extreme soil environment compared to the overlaying stratum (a decrease in water-retention capacity), as quite unsuitable can be considered its adsorptive ability, is carbon-free up to mildly limy although the soil reaction is rather strongly acid, and as for possible nutrients it is characterized by a low content of potassium and high supplies of calcium. Of the other evaluated elements the waste can be taken for toxic due to its content of manganese that exceeds 50 times a common field load considered for natural soils (Beneš 1994); high is also the content of total sulphur that reaches in the sediment up to 3.5%. Defined soil properties of the assessed anthropogenic soil are in Tables 1 to 3.

State of tree species assimilation organs

It is evident from the leaf analyses (Čermák 2006) that out of the investigated experimental plots (i.e. plots representing natural sites and plots occurring on settling basins) only the sediment depot is prob-

Table 1. Chemical and other special properties

Soil profile	Soil reaction (pH KCl)	Cation exchange capacity (cmol +/kg)	Degree of adsorptive saturation (%)	$CaCO_3$ (%)	N_{tot} (%)	C_{ox} (%)	Available nutrients (Mehlich III.) (mg/kg)			
							P	K	Mg	Ca
Overlaid stratum	3.8–5.7	20.7–23.5	< 30–54.0	< 0.1	0.19–0.21	2.4–2.9	14–31	193–197	114–155	928–2,413
Deposited sediment	3.0–4.5	< 5.0	< 30	< 0.1–0.5	< 0.05–0.06	1.0–1.2	33–46	11–71	42–61	10,703–15,452

Table 2. Hazardous elements

Soil profile	Total content (mg/kg)											
	As	Be	Cd	Co	Cr	Cu	Mn	Mo	Ni	Pb	V	Zn
Overlaid stratum	28.9–38.1	1.8–2.3	0.2–0.3	13.9–15.3	65.3–80.3	34.8–41.1	562–4,087	0.72–0.79	25.8–33.5	27.4–38.8	79.8–87.1	84.9–101.5
Deposited sediment	31.6–34.6	2.0–2.4	< 0.05–0.20	14.9–18.6	108.4–145.5	26.0–38.0	13,915–30,811	0.41–2.34	10.2–20.5	15.9–22.0	62.1–239.5	30.2–152.8

Table 3. Soil texture

Soil profile	Content of grain category (%)				
	< 0.001 mm	< 0.01 mm	0.01–0.05 mm	0.05–0.25 mm	0.25–2.0 mm
Overlaid stratum	16.2	33.2	21.7	32.3	12.8
Deposited sediment	< 4.0	14.4	17.5	54.2	13.9

Table 4. Contents of elements in assimilation organs

Locality	Tree species	N_{tot} (%)	P (%)	Ca (%)	Mg (%)	K (%)	Mn (mg/kg)	Fe (mg/kg)
1	*Alnus glutinosa* (L.) Gaertn.	3.41	0.23	1.22	0.29	1.05	291.8	288.2
2	*Pinus sylvestris* L.	1.44	0.11	0.52	0.10	0.47	104.0	212.9
3	*Quercus robur* L.	2.61	0.21	0.69	0.17	0.93	980.0	99.2
4	*Pinus sylvestris* L.	0.97	0.11	0.50	0.10	0.47	16.6	116.2
5	*Fraxinus excelsior* L.	1.93	0.33	2.34	0.40	1.24	41.4	87.9
6	*Acer platanoides* L.	1.45	0.21	1.49	0.23	1.17	1,277.0	71.8
7	*Acer pseudoplatanus* L.	2.22	0.32	1.03	0.15	1.44	2,011.0	43.8
8	*Tilia cordata* Mill.	2.51	0.25	1.05	0.27	1.67	1,118.0	150.6

Locality 1–2 – natural soil, locality 3–8 – sediment deposits

Fig. 1. Multiple trucks (*Tilia cordata* Mill.), frequent state of development also in *Betula verrucosa* Ehrh., *Acer pseudoplatanus* L., *Fraxinus excelsior* L., *Sorbus aucuparia* L.

Fig. 2. The state of the root system of *Pinus sylvestris* L. in the slope part of dump (taproot – twin root is not developed)

Fig. 3. The initial stage of *Pinus sylvestris* L. windfall (the static load of the set of horizontal roots is not in correlation with the developing aboveground part)

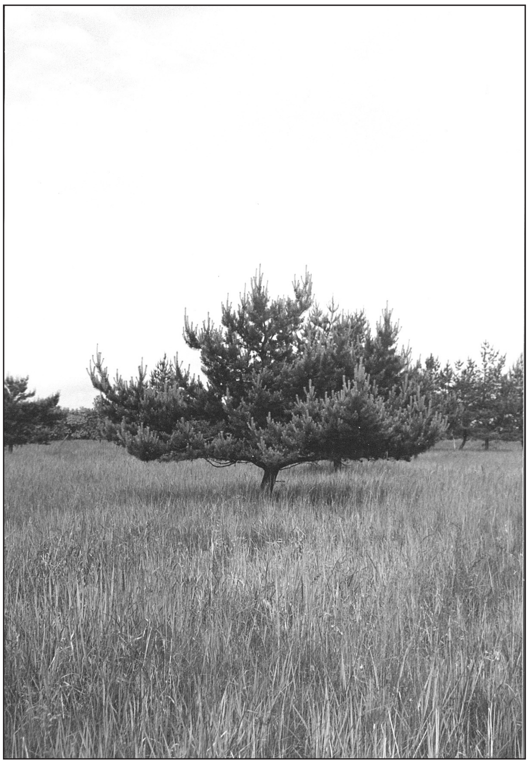

Fig. 4. Frequent developmental state in *Pinus sylvestris* L. (thickening of the basic part of stem, stagnation of height increment)

Fig. 5. The vegetation state characteristic of the dump surface damaged by water erosion with surface occurrence of deposited industrial waste

lematic from the aspect of nutrition; here the high content of manganese was determined in assimilation organs (the Mn:Fe ratio is quite unsuitable), except for *Pinus sylvestris* L. and *Fraxinus excelsior* L., of which a higher content of Fe is typical. The determined condition of evaluated woody plants may however be influenced to a different extent: by the heterogeneity of soils used for the dumpsite overlaying – sugar-factory sludge, spoil, strippings of Cambisol humus horizons in an opencast mine before the extraction started, by the character of the root system contact with deposited sludge and apparently also by different adaptability of tree spe-

Table 5. Taxa of tree species and frequencies of their occurrence in the assessed territory

Tree species	Occurrence
Broadleaves	
Acer platanoides L.	3
Acer pseudoplatanus L.	2
Fraxinus excelsior L.	2
Fraxinus americana L.	1
Quercus robur L.	1–2
Populus nigra L.	2–3
Populus tremula L.	1–2
Sorbus aucuparia L.	2
Tilia cordata Mill.	2–3
Betula verrucosa Ehrh.	2–3
Betula pubescens Ehrh.	2
Alnus glutinosa (L.) Gaertn.	1
Alnus incana (L.) Moench.	1
Malus sylvestris Mill.	1
Castanea sativa Mill.	1
Shrubs	
Crataegus laevigata D. C.	2
Ligustrum vulgare L.	2
Rosa canina L.	2
Corylus avellana L.	1–2
Cornus alba L.	1–2
Spiraea × *vanhouttei* Zab.	1–2
Physocarpus opulifolius L.	2
Conifers	
Pinus sylvestris L.	4
Pinus nigra L.	1–2
Picea pungens Engelm.	1–2

1 – isolated occurrence (2–3), 2 – distributed in groups (5–10), 3 – more groups (13–20), 4 – coherent stand (> 30)

cies to so called "toxic environment" (it is possible that some tree species physiologically utilize sludge from the industrial processing of pyritic shale or manganese ore). The contents of the other determined elements in assimilatory tissues correspond to common criteria given for woody plants in conditions of natural forest soils (Beneš 1994). Contents of elements in assimilation organs are presented in Table 4.

The knowledge concerning the creation of the suitable physiological depth of Anthroposols in recent formations for the "normal development of tree taxa" should be applicable to projections e.g. in conditions of spoil banks influenced by the coal seam substrates (pyrite presence, high acidity) or of dumpsites of power-plant side-products – stabilizate (high alkalinity, cementing effects).

CONCLUSION

Considering the type of deposited industrial waste the method of technical reclamation of the sludge dumpsite surface does not comply with the criteria that would provide a suitable soil environment for the development of tree taxa. The condition of aboveground and underground organs of woody plants reflects this evaluation, at the evaluated age of tree species (20–30 years) showing marked developmental deformations caused by nutritional disorders and inappropriate physiological depth of the Anthroposol profile. Currently, among the evaluated taxa the frequency of windthrows is highest in *Pinus sylvestris* L., in which the condition of the root system does not any longer satisfy the needs of the tree species for the type of biomechanical strain represented by the aboveground part (up to 36% of all individuals on the plot is damaged by complete or incipient windthrow). In all evaluated trees (100%) only sizeable systems of horizontal roots with numerous shorter oblique and vertical roots were formed that are placed in the overlaying stratum composed of reclaimable soil (0–0.4 m). The diameter of root penetration below the stem axis can be considered as atypical with respect to the tree species age, being 9–13.5 m in trees of breast-height diameter ($d_{1.3}$) 16–20 cm and crown width 2–3 m.

Based on the evaluation of the condition of aboveground organs (used significants) mainly *Populus nigra* L., *Fraxinus excelsior* L. and *Alnus incana* (L.) Moench. are important broadleaved tree species at the evaluated age of reclamation, along with *Fraxinus americana* L. and surprisingly also *Castanea sativa* Mill. (an underestimated tree species from the aspect of reclamations), *Pinus nigra* L., *Picea pungens* Engelm., from the introduced species, and the majority of shrubs. Surprising was the finding of a higher number of traits of damage (degeneration stage or growth stagnation) in *Acer platanoides* L., *Acer pseudoplatanus* L., *Tilia cordata* Mill., *Sorbus aucuparia* L., including some tree species generally appreciated from the aspect of reclamation (*Betula pubescens* Ehrh., *Crataegus laevigata* D.C., *Spiraea* × *vanhouttei* Zab.). The present condition of Anthroposol on the plateau and on slopes of the sludge dumpsite is considered as suitable only for grassing down or reforestation with shrub taxa from the aspect of reclamation.

Table 6. State of aboveground organs of tree species in the assessed territory

Tree species	Evaluation						
	A	B	C	D	E	F	G
Broadleaves							
Acer platanoides L.	1	1–2	+	1–2	1–2	3–4	+ –
Acer pseudoplatanus L.	1	1–2	+	1–2	1	4	+ –
Fraxinus excelsior L.	0	0		0	0–1	1	+ –
Fraxinus americana L.	0	0		0	0	0	–
Quercus robur L.	1	1–2	+	2	0–1	3–4	–
Populus nigra L.	1	0–1		0–1	1	1	+
Populus tremula L.	1–2	0–1		1	1–2	1–2	–
Sorbus aucuparia L.	1–2	2		1–2	1	1–2	
Tilia cordata Mill.	1	1	+	1	1	4	+
Betula verrucosa Ehrh.	0–1	0–1		1	0–1	4	+ –
Alnus glutinosa (L.) Gaertn.	1	1		1–2	1–2	2–3	+
Alnus incana (L.) Moench.	0	0–+1		0–1	0	0–1	–
Malus sylvestris Mill.	1	1		1	2	3	–
Castanea sativa Mill.	0	0–1		0	0	3–4	–
Shrubs							
Ligustrum vulgare L.	0	0–1	+	0–1	0–1	/	/
Rosa canina L.	1	1		1–2	1–2	/	/
Corylus avellana L.	1	0–1		0–1	0–1	/	/
Cornus alba L.	0	0		0	0	/	/
Spiraea × vanhouttei Zab.	0	0		0	0–1	/	/
Physocarpus opulifolius L.	1–2	1		1	1–2	/	/
Conifers							
Pinus sylvestris L.	1–2	–		1	1–2	–	+
Pinus nigra L.	0–1	–		0–1	1	–	+ –
Picea pungens Engelm.	0–1	–		0	0–1	–	–

A – defoliation, B – small leaves, C – chlorosis, D – malformation, E – crown desiccation, F – multiple trucks, G – basic stem thickening

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Poznatky z lesnické rekultivace odkaliště po průmyslovém zpracování manganopyritových břidlic

ABSTRAKT: Je popsána problematika lesnické rekultivace odkaliště odpadu po průmyslovém zpracování manganové rudy a kyzové břidlice ve stáří 20–30 let. Hodnotí se půdní vlastnosti antropozemě (překryvné vrstvy, deponovaných kalů), stav výživy asimilačních orgánů, vitalita nadzemních orgánů dřevin momentním vizuálním hodnocením pomocí doporučovaných makromorfologických kritérií a architektura kořenového systému borovice lesní (*Pinus sylvestris* L.).

Klíčová slova: lesnická rekultivace; odkaliště; manganové rudy; kyzové břidlice; antropozem; půdní vlastnosti; kořenový systém dřevin; růstová vitalita; fytotoxicita

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