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# FOREST RECLAMATION IN THE LUSATIAN COAL MINING DISTRICT (GERMANY)

**Key words:** Forest reclamation, soil amelioration, basal fertilization, growing-stock objective, stand formation

*S u m m a r y*

*This paper offers practical advice for the site adapted afforestation after lignite mining in Lusatia, Germany. The dumped substrates are characterized by low availability of nitrogen and phosphorous and are in most cases free of humus. Pyrite oxidation in Tertiary substrates leads to extreme acidity. However, these properties limiting plant growth can be modified by a site-adapted basal amelioration with limestone and special measures of NPK fertilization. Thereby, even on extremely acid sulphurous mine soils, productive forests can be established. In good agreement with the natural vegetation of the region the afforestation with common oak, sessile oak and small-leaved lime is favoured for better substrates, like carboniferous loamy sand or loam. On sandy and gravely mine soils with low sorption capacity mixed stands with Scots pine, sessile oak and birch are suggested. The afforestation (spacing, planting method, mixing proportion) should be carried out according to experiences from the reforestation of unmined locations.*

## Introduction

In the lignite mining districts of Eastern Germany forest reclamation takes up a key position for sustainable landscape development. Above all, the forests growing on the mine sites essentially contribute to ecological compensation and revitalization of the natural balance that has been severly disturbed by mining [Katzur 1997; Thomasius & Häfker 1998]. As a result nearly 60% of the reclaimed area in the lignite mining district of Lusatia is covered by forests (300 km$^2$). At present the annual rate of afforested areas amounts to 5 km$^2$.

However, afforestation of mine sites is considered to be complicated especially because of extreme chemical properties of the mine soils. As conse-

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quence the ecosystem nutrient cycle establishes with delay having a negative effect on initial stand development [Heinsdorf 1996; Katzur 1998; Knoche et al. 2002]. Beside this, the dumping of Quaternary and Tertiary substrates very often causes a small-spaced heterogeneous soil pattern, making the choice of tree species even more difficult [Thum 1974].

The first growing-stock objectives for the reforestation of mine sites based on soil properties by Lorenz et al. [1968, 1970] und Schwabe [1970] therefore favoured robust pioneer tree species with low site requirements like Scots pine (*Pinus sylvestris* L), birch (*Betula pendula* Roth.), northern red oak (*Quercus rubra* Du Roi), black and grey alder (*Alnus glutinosa* (L.) Gaertn, *Alnus incana* (L) Munch.) or asp (*Populus tremula* L.). However, in the long term the growth potential of many mine sites was clearly undervalued as various growth investigations in older stands show. Even on moderately cohesive and not optimum ameliorated substrates vigorous permanent stockings of deciduous trees can be established with sessile or common oak (*Quercus petrea* Liebl., *Quercus robur* L.), small-leaved lime (*Tilia cordata* Mill.) and hornbeam (*Carpinus betulus* L.), which may surpass the yield level of adjacent natural sites [Katzur et al. 2000; Wünsche & Selent 2000}. Therefore, a new orientation in forest reclamation is taking place, which follows the common trend towards near-natural forest management. As far as site conditions allow, ecological stable and high-yielding climax stands with a high portion of deciduous trees should be established on the mine sites.

This paper summarizes the present state of knowledge about forest reclamation on mine sites in the Lusatian lignite mining district. From this point of view, further practical proposals can be derived for the reforestation of other soils developing in loose rocks (e.g. after gravel and sand mining).

## Plant-bed preparation
### Amelioration

In the course of lignite mining frequently sandy to loamy Tertiary sediments containing high amounts of iron sulphides (pyrite) and lignite are dumped at the surface. Because of strong acidification (pH < 3.0) these substrates remain almost barren of vegetation [Knabe 1959; Pietsch 1996]. Without a suitable increase of pH reclamation is not possible. As the acidification potential of overburden material varies considerably accordant the lithofacies, it is necessary to calculate the lime requirement exactly for the different soil substrates and types of land-use. For this purpose it is advisable to calculate the so called „acid-base-balance“ [Illner & Katzur 1964] which has been used very successfully for agriculture and afforestation of acid sulphurous dump sites. It does not only refer to the actual acidity but also accounts the acidification potential by total pyrite weathering in order to achieve a sustainable soil pH increase [Katzur 1998]. Until 1990 in Lusatia predominantly basic ashes from lignite power plants were used for liming. However, today in reclamation practice fine-milled lime marls are used for reclamation almost exclusively.

Several long-term planting trials confirm that for all tree species optimum growth results can be achieved with target pH-values between 5,5 and 6,5 and a depth of lime incorporation between 0,6 and 1 m. Liming should always be related to 1 m soil depth, so that the translocation of lime by seepage water leads to a base transport into the subsoil [Knoche & Haubold-Rosar 2004]. Common deep rotary tillers (sandy and loamy soils) and fast-running rotary tillers (clay soils) are very suitable for incorporation.

Compared to this the afforestation of pyrite-free Quaternary substrates is rather favourable. With pH $H_2O$-values above 4,5 (substrates without carbonates) up to 8 (calcareous substrates) the base saturation usually reaches more than 60% and therefore is optimal for tree growth [Knoche 2001]. As a consequence amelioration measures are not necessary. Exceptional are compact clays and tills that may need a deep technical loosening. Latest trials in practice show that the use of powerful fast-running rotary tillers will create a loose and well aggregated soil structure up to 0,6 m soil depth.

## Fertilization

In general, the dumped raw soils have very low content of plant available nutrients, especially of nitrogen and phosphorous ($< 1$ mg·100 $g^{-1}$). Besides the critical soil reaction primarily the insufficient availability of nitrogen limits plant growth [Heinsdorf 1992]. It is true that in lignitic substrates the nitrogen content amounts up to 100 mg·100 $g^{-1}$, but in the beginning of soil development this nitrogen is hardly plant-available because it is strongly bound to fossil organic substances. Only step-by-step in course of the establishing of lignin degrading fungi it gets part of the ecosystem nutrient cycle [Knoche et al. 2000]. Therefore, a basal fertilization before planting and a supplement NP(K)-top-dressing are recommended to achieve a safe survival of forest plantations [Heinsdorf 1996; Katzur 1998; Thomasius & Häfker 1998]. For basal fertilization 50 to 100 kg·$ha^{-1}$ N, P or K are incorporated in the top soil layer. In case of higher lignite contents the application of nitrogen has to be increased. Optimum nutrient applications for the top-dressings range up to 300 kg N·$ha^{-1}$ and 100 kg P·$ha^{-1}$ (Table 1). They should be placed from the third year after planting when the root system has established and the nutrient reserves of the nursery plants have been used up. The application of nitrogen is carried out in 2 to 3 parts of 100 kg·ha$^{-1}$ each and with breaks of one to three years in between.

In the sapling stage the nutrition conditions in untreated and fertilized stands become adjusted. This relates to the establishment of natural element cycles and atmospheric nutrient inputs (nitrogen, phosphorous, base cations) [Heinsdorf 1996]. Therefore, older forests on mine sites show a well-balanced nutrient supply even in case of a moderate deposition level [Stähr et al. 2000]. Their nutrient turnover by crown leaching, litterfall and humus mineralization are similar to comparable forests in the surroundings of the mine sites, as a rule additional fertilization is not necessary [Knoche et al. 2002].

A significant improvement of the nutrient balance for the stand formation can also be achieved by application of easily degradable organic substances from waste materials (compost, sewage sludge) [Hüttl et al. 2004]. Hereby, the humus development can be clearly accelerated.

*Table 1. Fertilization of the main tree species on mine soils in the Lusatian Lignite Mining District (modified according to Heinsdorf 1999)*

| Tree species | Dumped substrates without lignite | Dumped substrates with lignite |
|---|---|---|
| Scots pine | $3N_{100}1P_{70}$ | $3N_{100}1P_{90}$ |
| birch | $3N_{80}$ | $3N_{80}1P_{80}$ |
| sessile/common oak | $3N_{100}1P_{50}1K_{40}$ | $3N_{100}1P_{100}1K_{40}$ |
| small-leaved lime | $3N_{100}1P_{100}1K_{40}$ | $3N_{100}1P_{100}1K_{40}$ |
| valuable broad-leaved trees | $3N_{100}1P_{100}1K_{40}$ | $2N_{100}1P_{100}1K_{40}$ |

$3N_{100}1P_{50}1K_{40}$ = three times fertilization with 100 kg N·ha$^{-1}$ each, in the first year in addition 50 kg P·ha$^{-1}$ and 40 kg K·ha$^{-1}$

## Afforestation

Major concern of forest reclamation is the safe formation of site adapted and well growing, vital stockings. As far as possible climax stands should be established in the first forest generation, which achieve multiple functions (protection and environmental conservation, production) with low management requirements. Based on the systematic analysis of numerous indicator plots on different mine sites [Thomasius et al. 1999; Böcker et al. 1999; Stähr 2003] a useful scheme for the selection of suitable tree species was derived (Table 2). The evolved growing-stock objectives correspond to combinations of tree species appearing by free succession in the terminal stage if negative effects such as acidification or compaction can be excluded. Therefore, a well-adapted basal liming of acid sulphurous mine soils is assumed.

In spite of the moderately dry lowland climate of the region only extremely nutrient poor and dry substrates like Quaternary gravel, gravel sand or coarse sand are left to undemanding growing-stock objectives with dominating Scots pine (*Pinus sylvestris* L.). Already on weakly cohesive sand with a low to medium trophy and moderate soil reaction (pH > 4,0) afforestation with sessile (*Quercus petrea* Liebl.) and common oak (*Quercus robur* L.) is possible. For more cohesive dumped substrates with a high nutrient status (trophy K and R) and growth optimum soil pH (5,5 to 6,5) mixed stands with valuable broad-leaved trees are recommended (common oak-small-leaved lime (*Quercus robur* L.-*Tilia cordata* Mill.), valuable broad-leaved trees (plane and sycamore maple, common ash)-common oak (*Acer platanoides* L., *A. pseudoplatanus* L., *Fraxinus excelsior* L.-*Quercus robur* L.).

*Table 2. Growing-stock objectives for mine soil afforestation in the Lusatian Lignite Mining District (terrestrial sites, ground-water table > 2 m below soil surface), modified according to Thomasius et al. (1999), Böcker et al. (1999), Knoche (2001) and Stähr (2003)*

| Dumped substrate | Trophy | Humidity | Growing-stock objective |
|---|---|---|---|
| calcareous loam and silt (partly with gravel or lignite) | rich (R) | moist to moderately dry (4-2) | common oak-small-leaved lime, valuable broad-leaved trees (plane and sycamore maple, common ash)-common oak, valuable broad-leaved trees-beech |
| | | dry (1) | sessile oak-birch, sessile oak-Scots pine, sessile/common oak-small-leaved lime |
| loam / loamy sand / silt / calcareous loamy sand with lignite | strong (K) | moist to moderately dry (4-2) | sessile/common oak-small-leaved lime/hornbeam, common oak-broad-leaved trees, beech-broad-leaved trees |
| | | dry (1) | sessile oak-birch, sessile oak-Scots pine |
| loam / loamy sand / lignite containing loam, loamy sand or silt / calcareous sand with lignite | medium (M) | moist to moderately dry (4-2) | sessile/common oak-small-leaved lime/hornbeam, sessile oak-beech, sessile oak-sycamore maple |
| | | dry (1) | sessile oak-Scots pine, sessile oak-birch |

| | | | |
|---|---|---|---|
| loamy sand / loamy sand and sand with lignite and gravel / pure sand (medium and fine textured) | low (G/Z) | moist to moderately dry (4-2) | sessile/common oak-Scots pine/birch |
| | | dry (1) | sessile oak-Scots pine/birch, sessile oak-birch, common oak-birch, Scots pine-birch |
| coarse sand / sand with lignite or gravel / gravel | poor (A) | moist to moderately dry (4-2) | pure Scots pine, pure birch, Scots pine-birch |
| | | dry (1) | pure Scots pine, pure birch, Scots pine-birch |

From the ecological point of view and in order to minimize management risks the formation of mixed stands is favoured. In doing so the scope for silvicultural planning is growing with increasing trophy and water storing capacity. For example, in pine stands on dumped sand only birch or asp are considered as admixture species. On the other hand Scots pine can be integrated in oak stockings which corresponds to the natural vegetation of the surroundings. Suitable ancillary tree species on loam soils with a high sorption capacity and sufficient water supply are small-leaved lime (*Tilia cordata* Mill.), hornbeam (*Carpinus betulus* L.), plane and sycamore maple (*Acer platanoides* L., *A. pseudoplatanus* L.), field and mountain elm (*Ulmus campestris* L em.Huds., *U. glabra* Huds.), in areas with higher annual precipitation (> 700 mm) also beech (*Fagus sylvatica* L.) and common ash (*Fraxinus excelsior* L.). Furthermore, the admixture of rare and native ancillary tree species (e.g. *Acer campestre* L., *Ulmus spec*., wild fruit woods, *Salix spec*., *Sorbus aucuparia* L.) and bushes (e.g. *Rosa canina* L., *Prunus spinosa*, *Crataegus monogyna* Jacq.) is possible in small groups. This contributes to biodiversity and landscape aesthetics (e.g. design of forest edges). The admixture of non-authochton tree and bush species is refused.

After 20 to 30 years of stand development the forests on the mine sites reach conditions comparable to the stockings on the surrounding sites (growth dynamics, ecological status, nutrient turnover, water budgets). As the survival rates of the young stands are comparable too (nearly 80 to 95%), the necessary number of plants can orientate at the general forest guidelines. This is also valid for the proportions and forms of mixture. Table 3 shows a survey of plant numbers recommended for the afforestation of mine sites. In case of simultaneous planting of admixture species the listed plant numbers have to be adapted according to mixture proportions. The form of mixture is oriented by the potential crown area of mature trees and should ideally be planned in groups or nests. In reclamation practice admixtures in rows are preferred because of dominating machine planting.

*Table 3. Scope of spacing and mixing proportion for mine site afforestation*

| Tree species | Plants $ha^{-1}$ | Admixture species | Plants $ha^{-1}$ |
|---|---|---|---|
| Scots pine | 6.000-8.000 (10.000-12.500)[1)] | birch, sessile oak, asp | 6.000 |
| sessile/common oak | 5.000-7.000 (8.000-10.000) | small-leaved lime, hornbeam | 3.000 |
| valuable broad-leaved trees | 6.000-8.000 | valuable broad-leaved trees, beech | 2.000 |
| black alder | 2.500-3.500 | common ash | 1.000 |
| birch | 2.000-3.000 (2.500-3.500) | sessile oak, Scots pine | 2.000 |

[1)] informations in brackets refer to pure stand formation

Despite quite difficult site conditions and initial growth depression the chosen tree species can be established without a pioneer crop stage. However, associate vegetation appearing spontaneously should be assessed positively because of its impacts on soil and ecosystem development. Especially low-growing herbs have favourable effects like temporary nutrient storage, accumulation of organic substances or soil aggregation. An alternative is the co-cultivation of protective or auxiliary plants. On sites with a medium to rich nutrient status and moderately dry to moist conditions leguminous plants binding atmospheric nitrogen can be recommended. However, on poorer sandy soils the seeding of rye (*Secale multicaule*) in moderate rates of about 10 $g \cdot m^{-2}$ has proven its worth. Such measures obviously improve the survival rate of the trees and their height growth during the first years. However, higher sowing rates create negative effects on the stand formation as a consequence of intense competition.

If the management goal is not endangered the natural seeding of birch, poplar, alder and willows can be tolerated as an open pioneer crop cover. Mainly on sites with a medium to rich nutrient status this causes a positive ecological impact by improving the stand structure [Ertle 2005]. The turnover of easily degradable leave litter accelerates the soil formation (accumulation of humus); black and grey alder are well-known for their ability to bind atmospheric nitrogen. Only out competing long grasses (e.g. *Calamagrostis epigejos*) and nitrophile ruderal plants like die blackberry (*Rubus spec.*) justify measures against the associate plants. However, herbicide application should be avoided especially on the raw soils that are still unpolluted.

## Conclusions

The shown scheme of growing-stock objectives gives practical advice for the site adapted afforestation of mine sites. However, the influence of the amelioration quality on vegetation development can not be foreseen without any doubts in the long term. The indicator plots analyzed up to now are at most 40 years old and amelioration technology has changed a lot during this. Despite increasing expenditures of soil mapping and considerable technical progress the results of soil amelioration do not always agree with the objectives.

Also the afforestation of dumped substrates with high contents of clay is problematical up to now. Still experts can not base the tree species selection on planting trials. The present stocking recommendations are essentially derived from investigations on hydromorphic natural sites by inadmissible analogical conclusions. Specific soil physical properties of the anthropogenic substrates like poor aeration, oxygen deficiency or compaction and impeded rooting are not considered yet. Especially because of the recompaction that has been observed after deep-loosening measures, there are variousuncertainties concerning the climax forest types and site adapted tree choice.

Besides basal amelioration the use of fertilizers is essential for a successful stand formation. In reclamation practice fertilizer application aims to optimize nutrient supply and biomass production. It is still not clear if a sufficent survival rate of forest plantations may be guaranteed with considerably reduced amounts of fertilizers. Furthermore, there is lack of systematic investigations about the effects of protective plants on soil and stand development. However, this is important, especially with regard to a fast establishment of the ecosystem nutrient cycle and thus wanted saving of mineral fertilizers.

At least there are evident deficits concerning the evaluation and classification of mine sites. So soil mapping traditionally focuses on assessment of soil chemical properties. The soil water storage capacity as an essential factor of plant growth as well has got much less attention in the past. But in fact lignite particles and clay or loam clots considerably improve the soil water budget of dumped sandy substrates. Furthermore, the site potential is decisively determined by the rooting of the substrates which especially depends on the quality of soil amelioration. Neither the common mine site survey method nor the official site mapping guidelines for unmined forest locations are suitable for an adequate representation of these most growth relevant properties. In addition, it has to be marked that the trophy categories used in the classification system for the mine soils do correspond hardly with the system that has been evolved for natural forest soils (e.g. no consideration of the total contents of Ca, Mg, K, P). Therefore, a further development of the mine site mapping methods and an adjustment to the site mapping methods for natural sites should be taken into account.

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