Field Trial of Iron Hydroxide Sludge for Revegetation and Improved Productivity of Structurally Weak Soils

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Abstract

In Eastern Germany the majority of the open-cast mines in the former GDR that could not be privatized were taken over by the federal government and the lignite states (LMBV) with the aim of rehabilitating them. In this area iron hydroxide sludge (IHS) is produced as a result of diffuse groundwater inflow into watercourses. This sludge is removed regularly from the riverbeds as a part of remedial action. In addition to iron , the sludge contains high concentrations of organic compounds.

The suitability of this IHS for improving the productivity of overburden soils was tested in a three-year field trial. To date, IHS appears to be suitable for soil improvement, both physically by facilitating storage of rainwater and biochemically through availability of minerals and nutrients for vegetation. There is a clear improvement in the growth conditions of the cultures tested.

Field trial results presented here demonstrate, that soil supplements from IHS can improve the fertility of structurally weak overburden soils if environmental regulations can be met. Using the sludge as a soil amendment reduces waste and supports sustainable, circular economy.

Keywords: Iron Hydroxide Sludge, Soil Productivity, Sustainability

Introduction

The Lusatian and Central German Mining Administration Company (LMBV) is responsible for remediation of former lignite mining legacy sites in Lusatia / Eastern Germany (Bund 2022). This requires water management, especially the replenishment of ground water deficits, creation of safe pit lakes, their connection to the public water system, and the improvement of water quality. Large amounts of iron hydroxide sludges (IHS) are produced, both in water treatment plants and through diffuse groundwater inflow into watercourses, where reduced iron is oxidized and precipitates as oxyhydroxide minerals. In addition to high iron content, IHS from riverbeds contains high concentrations of organic compounds. LMBV is working to recycle these sludges as much as possible.

When the post-mining landscapes in Lusatia are rehabilitated, large dump areas made of sandy overburden material remain, without fertile soil horizon. Revegetation in preparation for subsequent agricultural and forestry use requires the addition of fertilizer and lime. Here, we report the results of a pilot project which examined whether sludge collected during clearing of watercourses would be suitable for improvement of structurally weak overburden soils.

Suitability of iron hydroxide sludge

The occurrence of iron compounds in soils is natural. Iron oxide compounds directly influence the fertility of soil. Plants meet their metabolic iron requirements using ferrous and ferric iron organic acid complexes, (fulvic and humic acids) and using organic substances in the root area. Beyond being a nutrient, iron contributes to soil improvement forming amorphous iron minerals with a large specific surface area that can store large amounts of nutrients (UPT 2016). Further, iron precipitated from pore water within the soil acts as a mineral cement (concretion), and therefore reduces erosion.

Legal regulations

The Circular Economy Act (Bund 2012) must be observed when dealing with IHS. This requires that materials should be avoided if possible, before recycling, subaqueous disposal in post-mining lakes, and placement in a surface dump can be considered. The aim is to conserve natural resources and manage waste in an environmentally friendly manner. When using IHS to improve the productivity of soil, the applicable statutory provisions of the Federal Soil Protection Act (Bund 1998) and waste legislation must be observed.

Before further use, dredged material from the clearing of riverbeds must be characterized with respect to pollutant and physical properties. This step is also essential due to the strong spatial heterogeneity of the IHS and the seasonal material dynamics of many state variables, for example TOC. This ensures that its application to the soil does not negatively affect the soil quality. Prior to this field test, characterization analyses and ecotoxicological tests were carried out on IHS from various origins. Risks were assessed based on these data to chose suitable IHS.

Not all IHS occurring in the area regulated by the LMBV can be used for soil improvement. In particular, IHS with increased arsenic concentrations (i.e. > 20 mg/kg) were excluded from this study. The ecotoxicological tests on the living conditions of the soil organisms showed a) no negative effects with an admixture of 12.5% IHS, and b) no lasting negative effects with an admixture of 20% IHS. Only IHS met soil protection law and ecotoxicology requirements was used for the test.

Conceptual design of field test

The effect of IHS was tested both on trees and on a grass-herb mixture. An organic component (K3) was used in the test for comparison purposes. Admixture proportions of 12.5 or 20% IHS and 5% organic component (K3) in various combinations were compared to an untreated test area as described in figure 1.

A typical regional herb-grass mixture was chosen that is commonly used in re-cultivation work in Lusatia. This consists of perennial rye, perennial lupine (alfalfa), brown mustard, radish and four clover variations. In tree trials, the typical trees birch, oak and pine were used.

The field tests were conducted at the former Spreetal opencast mine (Saxony, Germany) within a 30,000 m^2 test area filled with quaternary silica sand. The amended area was compacted and levelled prior to planting.

Methods

Prior to the addition of IHS, the test areas were delineated and the existing substrate was analysed physically and chemically.

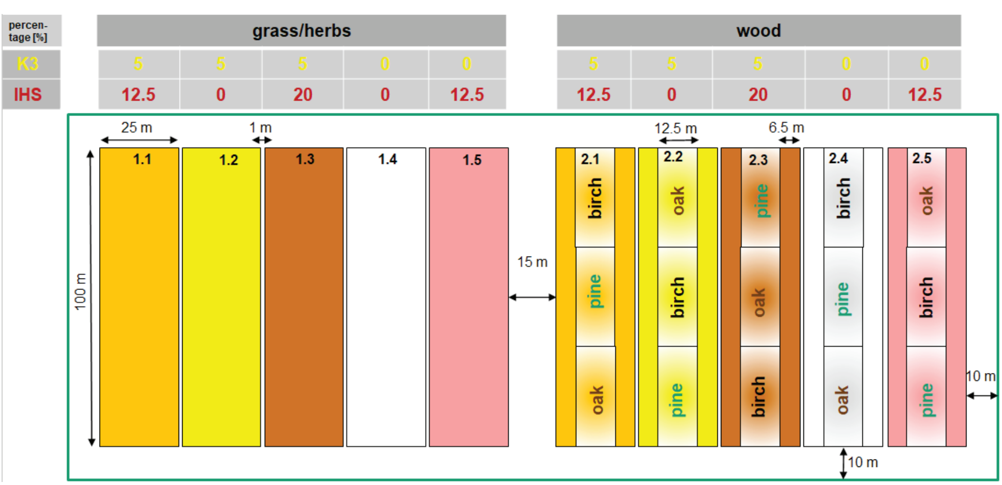

Figure 1 *Field trial experimental design showing geometry, amendment percentages and type of planted vegetation*

The supplied IHS was screened before it was incorporated into the soil to remove macroscopically visible foreign matter (e.g., wood debris, coarse rock, etc.) The existing substrate was loosened and soil supplements were applied in the areas to a depth of 0.3 m for the grass-herb mixtureand to a depth of 0.75 m in the areas planting with trees.

As shown in Figure 1, specific areas of the test field were planted with different species: 900 Silver Birch trees (*Betula pendula*) were planted. These pioneer trees are fast-growing and can establish on nutrient-poor, acidic soils. The Common Oak (*Quercus robur*) was established with 1,200 specimens. Widespread in Central Europe, it shows good growth performance on nutrient-poor sandy soils, especially when young. 2,500 Scots Pines (*Pinus sylvestris*) were planted as conifers. This species is also relatively undemanding and therefore also suitable for nutrient-poor sandy soils.

Seeding and planting took place in May 2020. As the spring of 2020 was very dry and there was no water in the ground from the snowmelt, all test areas were watered (approximately 3 mm) before seeding and planting. Further irrigation and fertilization of the test field was deliberately avoided in order to collect data under the prevailing natural conditions.

Separation foils were placed between the individual test areas to reduce erosive displacement of substrate between the individual testareas as well as the unwanted migration of plants from the grass-herb mixture during the field trial. A protective fence was erected to prevent browsing damage with accessibility ensured via a wide gate. An observation well was installed in the outflow of the test area and regularly monitored to prove that the seepage water discharged to groundwater is harmless.

Monitoring

In the three years between 2020 and 2022, the growth of the trees, grasses and herbs was monitored several times a year, especially at the beginning and end of the vegetative growth period. The growth height and the degree of coverage were examined on site on the test areas with grass-herb mixture. The above-ground phytomass and dry matter were determined in a laboratory by weighing and drying and weighing (fig. 2).

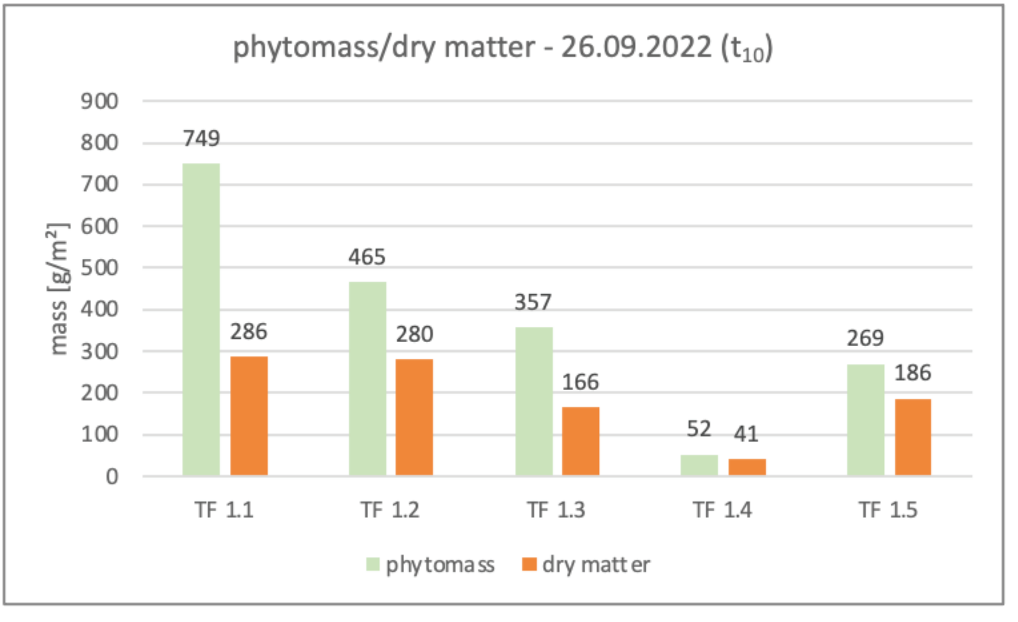

Figure 2 *Grass and herb above-ground phytomass 09/2022 (IEC 2022)*

Figure 3 *Birch growth height and trunk diameter 09/2022 (IEC 2022)*

Twenty-four randomly selected trees were monitored per planting unit. The growth height and trunk diameter were measured (fig. 3), and vitality was determined using a tree growth method. Samples of solids and water were analyzed from all test areas in order to record possible changes in the soil chemistry. In addition, meteorological conditions were recorded.

Results and discussion

Amendment with IHS added iron, manganese, and calcium to the soil. The arsenic content in the IHS selected for the experiment was significantly lower than the geogenic concentrations in the dump sands, which were generally less than 5 mg/kg. The IHS amendment therefore did not increase arsenic soil concentration. In addition, no increase of metals such as cadmium, chromium, nickel, mercury, and lead was determined through the application of IHS, shown by chemical analyses. Except for the untreated sub-areas (TF1.4 and 2.4), the measured pH values in the soil fluctuated around 6.0, ensuring a good nutrient supply under slightly acidic conditions.

To date, the pilot test shows that IHS is suitable for soil improvement, both physically through better storage of rainwater and biochemically through storage and improved availability of nutrients for vegetation.

The improvement of the soil structure and the fertility of the soil was proven with monitoring: Both the grass-herb mixture and the tree plantings grew significantly better with IHS input compared to the untreated subfields. These results were achieved despite additional stress of above-average temperatures and below-average precipitation during the three growing seasons.

The value of the IHS as a water-storing substrate is particularly evident from the degree of coverage (fig. 4 to 7). No negative change in water quality of the groundwater is evident in the data. The groundwater quality has been the same. Optimum growth conditions were achieved for grasses and herbs with an admixture of 5% by volume of the organic component (K3), with the addition of either 20% or 12.5% by volume IHS. The best growth results were achieved for the woody plants with 12.5% by volume IHS amendment and 5% by volume of organic component (K3). After three years, the dry matter of the grass-herb mixture on the treated test areas (TF 1.1 – 1.3 and 1.5) is at least 4 times higher than on the untreated reference area (TF

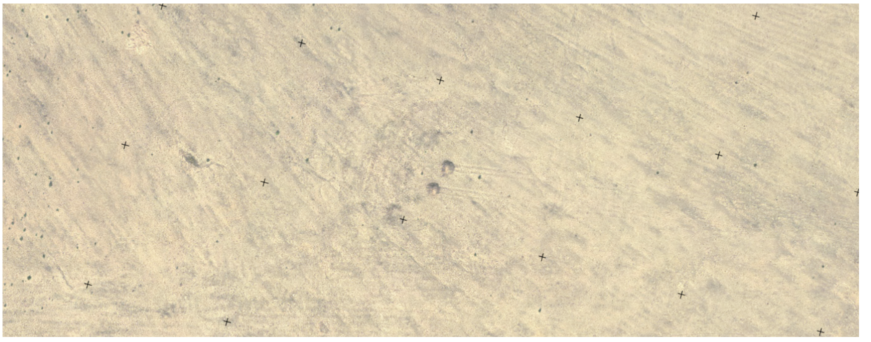

Figure 4 *Aerial photo – test field (300 x 100m) before the start of the test (10/2019)*

Figure 5 *Aerial photo – test field (300 x 100m) after the start of the test (06/2020)*

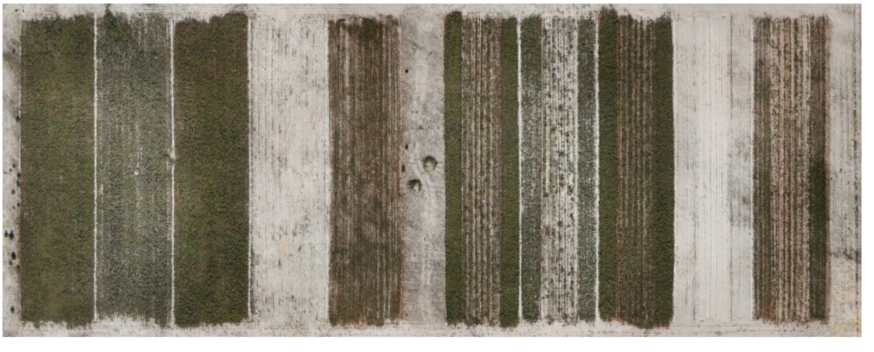

Figure 6 *Aerial photo – test field (300 x 100m) after two growing season (09/2021)*

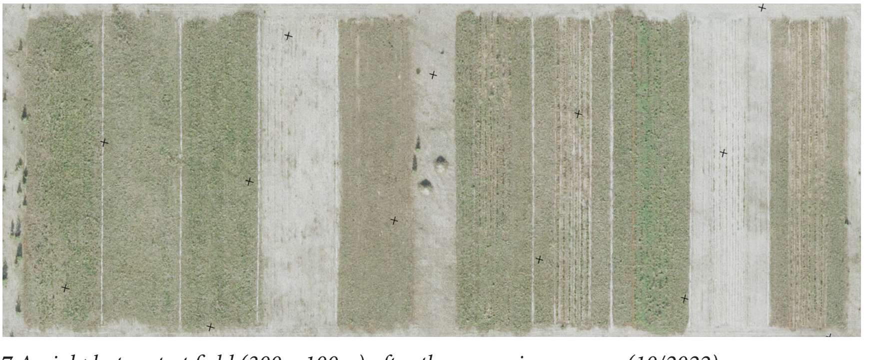

Figure 7 *Aerial photo – test field (300 x 100m) after three growing seasons (10/2022)*

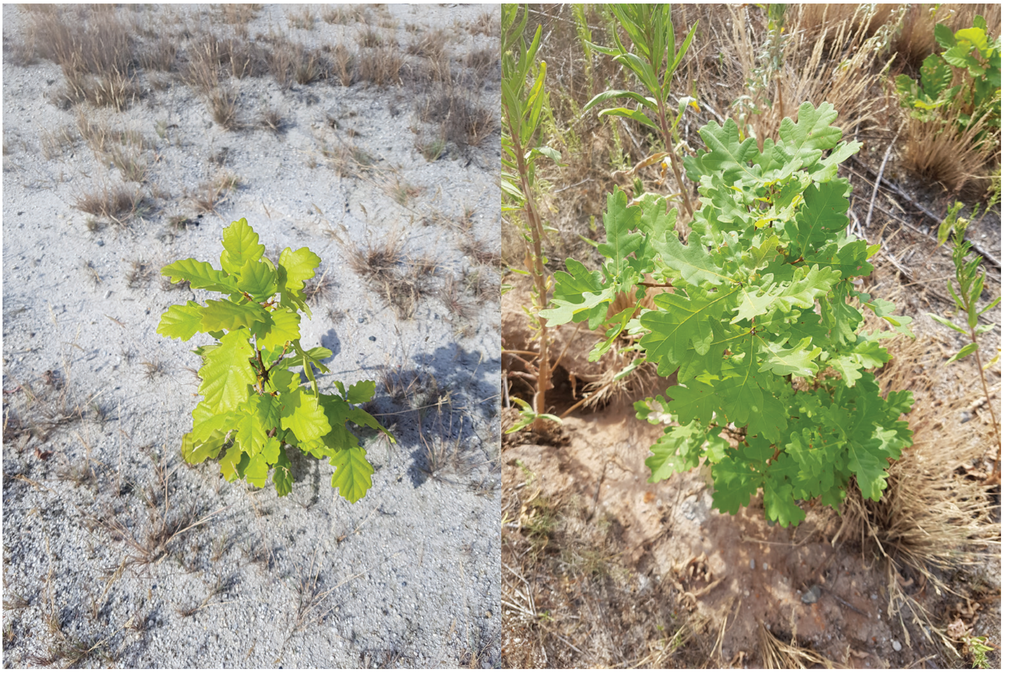

Figure 8 *Oak on untreated test area 2.4 (left) and test area 2.5 (right) treated with IHS (08/2022)*

1.4) (fig. 2). After three vegetation periods, the trunk diameter and growth height of the birches on the treated test area (TF 2.1 – 2.3 and 2.5) are at least twice as high as those on the untreated test area.

Long-term predictions for the development of woody plants are still hypothetical, because equilibrium between development, degradation and conversion processes of material and energetic resources between vegetation and soil can only occur at climax stage of the stands. However, it is expected that the future development of the trees will be comparatively better on the areas treated with IHS, as water and the nutrient cycling conditions have improved equally. Monitoring will be continued on the test area for long-term observations. This approach offers both economic and ecological value in terms of sustainability. As a next step, the LMBV is planning a large-scale test to improve the productivity of dump soils on an area of around 500,000 m^2 in Lusatia, with subsequent use for agriculture and forestry.

Conclusion

A three year field trial has demonstrated that the fertility-determining parameters of quaternary overburden sands improved following the addition of IHS and organic amendment K3. In addition to an improved storage and availability of nutrients for vegetation, physical properties were enhanced through better storage of rainwater. As such, IHS, commonly considered as waste material, can be utilized in the sense of circular economy and sustainability.

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