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SELECTING MATERIALS FOR MINE SOIL CONSTRUCTION WHEN ESTABLISHING FORESTS ON APPALACHIAN MINE SITES

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The Forestry Reclamation Approach (FRA) is a method for reclaiming coal-mined land to forest (FRA Advisory #2, Burger and others 2005). The FRA is based on research, knowledge, and experience of forest soil scientists and reclamation practitioners. Forest Reclamation Advisories are guidance documents that describe state-of-the-science procedures for mined land reforestation (see http://arri.osmre.gov/FRA/FRA.shtm).

The FRA's first step is: "create a suitable rooting medium for good tree growth that is no less than 4 feet deep and comprised of topsoil, weathered sandstone and/or the best available material." This Advisory provides guidance on how to execute step 1 of the FRA.

Selection and placement of suitable growth media are critical for successful reforestation on surface mines. Constructing mine soils using suitable materials enhances and accelerates development of diverse forest ecosystems. This Advisory is intended for mining operators seeking to re-establish native forest as a post-mining land use with pre-mining capability on coal surface mines.

Background

Soil is a mixture of weathered rocks, organic material, water, air, and living creatures. Its properties provide the structural support and other resources necessary for plant and animal life in a forest. The soil is the foundation of a forest ecosystem. Indeed, the health and productivity of a forest are determined by the nature and properties of the soil.

The eastern USA's Appalachian Mountains are among the world's most ancient landscapes. The region's soils have developed from the rocks that form these landscapes over long time periods in response to climate, plants and animals, and landscape position (Jenny, 1941). Throughout the Appalachians, diverse plant communities have evolved over millennia on these weathered rock and soil materials (Figure 1).

Weathering is the process of changing rocks into soil-like materials. During surface mining, unweathered rocks are often placed on the surface as growth media. These rocks react with air and water and break down physically and chemically, releasing soluble salts and changing mineral forms (Sencindiver and Ammons, 2000). Plants can establish and grow in these pre-soil materials, producing organic matter to aid soil development and making the growth media more favorable for colonization by microorganisms and other plants (Johnson and Skousen, 1995). These processes are well known, occur naturally, and can be accelerated by reclamation activities such as fertilizing and seeding. However, when starting with unweathered rocks, very long time periods are required to produce a soil that can support a plant community like the one which existed before mining (Figure 2).

Figure 1.
The Mixed Mesophytic Forest of the Appalachian mountains is a diverse assemblage of over 40 tree species that depend on native soil properties and other environmental factors

Figure 2. The native soils of Appalachia (left) develop over long time periods and have properties that are well suited to supporting native forest ecosystems (right).

While unweathered gray rock materials brought to the surface during mining will eventually weather into soils, they are generaly not suitable for restoring pre-mining forest capability. Forest development can be accelerated by using the natural soil and/or weathered brown rock materials to reconstruct the land surface (Figure 3). Salvaged soils and weathered rocks are superior to unweathered gray rocks as soil substitutes because of their superior ability to supply nutrients, air, and water to plants (Figures 4-7). Hardwood trees and other plants that are native to Appalachian landscapes have evolved to grow in the region's soils and near-surface weathered rocks (Smith, 1983; Torbert and Burger, 2000).

Figure 3. In the background is the native plant community growing on native soils. In the foreground, the native soil has been stripped off of the surface. The overburden consists of the weathered brown sandstone over unweathered gray sandstone and siltstone.

SMCRA

The Surface Mining Control and Reclamation Act (1977) requires that reclamation practices shall "restore the land affected to a condition capable of supporting the uses which it was capable of supporting prior to any mining, or higher or better uses of which there is reasonable likelihood ..."[1] The guidelines recommended here are intended to be consistent with SMCRA, and to allow mine operators to achieve that SMCRA requirement when reclaiming lands to forest.

Forested land requires deep soil for productive tree growth (Torbert et al. 1988; Andrews et al. 1998), SMCRA requires removal and replacement of "topsoil" unless a variance from that requirement is obtained. Under SMCRA, the term "topsoil" is often used to describe the upper soil horizons, or the upper 6 inches of soil. Salvaging and re-spreading only the upper few inches or horizons of soil is unlikely to restore pre-mining capability unless additional materials suitable for reforestation are added. Federal regulations state that "selected overburden materials may be substituted for, or used as a supplement to topsoil if the operator demonstrates to the regulatory authority that the resulting soil medium is equal to, or more suitable for sustaining vegetation than, the existing topsoil, and the resulting soil medium is the best available in the permit area to support revegetation."[2] Here, we provide guidance for practices that may be used to satisfy that requirement when restoring mined land as forest.

Guidelines

1. Salvage and re-spread soil (except where the operation would compromise machine operator safety).

The term "soil," as used here, refers to all surface soil material to a depth of broken bedrock that can be removed with a dozer. Soil includes the O, A, E, B, C, and R soil horizons. Soil to be salvaged for re-spreading should include soil organic matter and plant materials such as tree stumps, roots, branches, and leaves remaining from harvested trees; and rocks found within the soil profile. The best soil materials for reforestation are those with the most organic materials, i.e., those which occur closest to the surface.

Soils from forested areas contain materials that aid plant community development on reclaimed mines. Three properties of soil make it especially valuable for reclamation when re-establishing forests.

Figure 4. Weathered brown sandstone on a West Virginia mine site has formed a mine soil that supports good tree growth and has good colonization of native plants after two years. Mine soil pH is 6.0. The experimental areas on this mine site were not seeded with ground cover.

Figure 5. Unweathered gray sandstone on the same West Virginia mine site as in Figure 4 after two years shows some weathering into smaller particles, but has shown generally poor tree growth and poor colonization by native plants. The pH is above 8.0.

Figure 6. The same mine site as Figure 4, with weathered brown sandstone, six years after planting with native hardwood trees. Good growth by trees and herbaceous plants is evident.

Figure 7. The same mine site as Figure 5, with unweathered gray sandstone, six years after planting with native hardwood trees. Although planted trees are surviving, growth is poor. Soil pH remains above 7.5.

First, viable seeds and propagules contained in the soil (called a *seed bank*) enable restoration of native forest species (Hall and others, 2010). Second, organic matter in the native soil contains nitrogen and phosphorus, soil nutrients essential for plant growth that are not readily available to plants growing in unweathered mine spoils. Third, soil-dwelling animals and microorganisms in the forest soil aid in providing and cycling nutrients for plants, create channels for air and water movement, and promote favorable hydrologic properties.

Soil should be considered a “living resource” and re-spread immediately when possible to maintain living soil animals, microorganisms, roots and seeds. When soil is obtained from forested areas prior to mining, the salvage operation should take stumps, roots, and woody debris left on the site, transport them to the reclaimed area, and re-spread them with the soil.

Even if salvageable soil is not available in quantities sufficient to produce an adequate depth over the entire reclamation area, replacement of fresh soil over portions of the reclamation area and/or mixing salvaged soil with other overburden materials will aid re-establishment of a native forest plant community, and it will aid restoration of essential ecosystem processes on the reclaimed mine land.

If graded to a smooth surface, and especially if lacking rocks and organic debris, salvaged soil may be more prone to erosion initially than the rocky spoils used in some reclamation practices today. Thus, when a slow-growing tree-compatible ground cover is used, some soil erosion may occur during the first year or two as the seeded and volunteer vegetation becomes established (see FRA Advisory #6, Burger and others 2009). However, a surface that is loose, rough with small depressions, and contains forest-floor rocks and organic debris enhances water infiltration, reducing runoff and surface erosion.

When both salvaged native soils and other materials are being used for mine soil construction, "mixing" is accomplished by hauling and dumping materials, and then by lightly grading the surface (Figure 8) or with the use of other equipment to level the surface (Figure 9) (FRA Advisory #3, Sweigard and others, 2007). *It is essential that spreading be done in a manner that avoids soil compaction.* Additional equipment operation to mix these materials more thoroughly should be avoided to reduce the potential for compaction of the surface layers.

Figure 8. Mixing of soil materials can be accomplished by transporting them to the site, dumping them in adjacent piles, and then lightly grading the materials.

2. Where available and of suitable quality, weathered spoil materials, and most especially sandstones, should be salvaged and re-spread to supplement soil materials.

Weathered materials can be easily recognized on most mine sites by their brownish colors (Figures 3 and 10). They are found just below the surface, usually within the upper 10 to 30 feet. Weathered sandstones, if available, will generally be superior as reforestation growth media to weathered siltstones and shales. Weathered sandstone will generally have a pH of 4.5 to 6.0.

Weathered rocks are not suitable as growth media if they are extremely acidic or contain pyritic materials that will cause water quality problems if used on the surface (Isabell and Skousen, 2001). If soil pH is below 4.0, it probably contains acid-producing minerals and should not be used.

Some weathered sandstones are low in essential plant nutrients, and mixing these materials with weathered siltstone or shale may improve soil fertility (Showalter and others, 2010). Soil tests can predict available nutrient levels in these materials.

Figure 9. An excavator can be used to level dumped topsoil piles without causing compaction and can be quite useful when the dumped soil piles contain stumps, logs and other coarse woody debris.

3. When soil and weathered brown sandstone are not available in adequate quantities, selected unweathered overburden materials with suitable properties can be used as supplemental materials.

Just as a brown color can distinguish an overburden's weathering status, white and gray colors often indicate unweathered materials. Generally these materials when used alone will not support either rapid tree growth or rapid re-colonization by native plants (Figure 7) (Emerson and others, 2009; Angel and others, 2008). On remining sites, however, very little topsoil or weathered materials may be found. On these areas, almost exclusive use of unweathered materials as the growth media may be unavoidable. In such cases, selection of the best available material should be based on physical and chemical tests that indicate likely suitability for trees. Unweathered overburdens that contain no pyritic minerals, are composed of rocks that break down to form soil-like materials when exposed to air and water, have relatively low levels of soluble salts, and weather to generate soil pH in the 4.5 to 7 range will form better growth media for forest trees than other unweathered spoil materials.

Figure 10. Weathered overburden can be found immediately below the soil and often extends to about 30 feet beneath the surface – although it may be deeper. Under the weathered overburden are unweathered materials as shown in this photo. The weathered overburden, which has been affected by surface processes, is better material to place on the surface for forestry land uses than unweathered gray materials.

If soil and weathered materials are available but not abundant, selected unweathered materials of primarily sandstone with small amounts of shale and siltstone can be used (Conrad, 2002; Burger and others, 2007).

We have documented mine sites where soils comprised of weathered overburden support tree growth comparable to unmined forests (see Box 1), but we are not aware of mines reclaimed with only unweathered spoils that have achieved pre-mining productivity levels.

4. Avoid surface placement of materials that are unsuitable as growth media for native forest trees.

Properties of spoil materials that will make them unsuitable for reforestation are:

i) Content of coarse fragments (>2mm particles) of >60% by mass that will not break down rapidly into smaller particles; such as materials typically used as durable rock (Daniels and Amos, 1984; Haering and others, 1993; Sencindiver and Ammons, 2000).

ii) High pH (>7.5).

iii) Content of pyritic minerals sufficient to produce soils with pH <4, and to generate acids and excess salts, thereby elevating total dissolved solids (TDS) in runoff waters; generally, materials with > 0.1% sulfur contents will be unsuitable.

iv) Minerals that will produce high levels of soluble salts. Selected materials should achieve electrical conductivities of <1000 µS/cm, as measured using methods commonly applied in soil analysis[3], when trees are planted. Generally, raw spoils with electrical conductivities >1000 µS/cm, as measured using a method applied to raw spoils[4], will be unsuitable.

v) Carbonaceous rocks such as "black shales" are usually unsuitable;

Materials with these properties should be avoided when constructing growth media for reforestation of coal surface mines. .

Some mine sites, such as remining sites in areas where pyritic materials and shales are common, may lack materials suitable for reforestation to achieve pre-mining productivity. Operators on such sites should obtain expert assistance in selecting the best available materials. Material selection for reforestation on such sites is not addressed by this Advisory.

Summary

When native forest re-establishment is the post-mining land use and reclamation goal, the guidelines reviewed in this Advisory (see Table 1) can aid mine operators in ensuring that mine soils, applied at a minimum of 4 feet in thickness, will restore land capability and support forest growth and diversity at pre-mining levels.

Step 1 of the FRA is intended to "create a suitable rooting medium for good tree growth that is no less than 4 feet deep and comprised of topsoil, weathered sandstone and/or the best available material." These guidelines are intended to inform mining operators who are using the FRA.

An ability to restore native forests on mined lands after mining will be an asset to the Appalachian coal industry as it seeks to demonstrate its capability to mine coal in Appalachia while protecting and restoring environmental quality. These guidelines can be used by the Appalachian coal industry to restore productive and diverse native forests after mining.

Table 1. Summary of material types and guidelines for constructing forestry mine soils on Appalachian coal surface mines.

Type	Description	Use
1. Soil	Pre-mining forest soil; includes mineral horizons, rocks, stumps, roots, and seed pool as well as soil-dwelling animals and microorganisms.	Use if available; usually the best available material.
2. Weathered rock	Brown rocks that lie beneath the soil prior to mining.	Mix with (1) if necessary to achieve adequate quantity for ≥4 foot depth; sandstones are best.
3. Selected unweathered rock	Rock below weathered strata, usually gray, that weathers within a few years to pH 4.5-7.0, has relatively low soluble salts, and breaks down to form soil-like material.	If (1) and (2) are not available in adequate quantities to produce a mine soil of ≥4 foot depth, (3) may be mixed at up to 2:1 ratio with (1) and/or (2).
4. Unweathered rock to avoid	Have pyritic minerals, high pH, and/or high soluble salts; or is durable rock or black shale.	Avoid use for forestry mine soils, either alone or in significant quantities within mixes.

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BOX 1: Scientific Background for Material Selection Guidelines

Research and practice have shown that the FRA, when applied correctly and completely, will restore forest vegetation on mine sites. Numerous studies show that the FRA's first step of selecting and properly placing good soil materials is critical for productive, diverse forest reestablishment.

Soil is an excellent material for mine soil construction. Use of fresh soils as plant growth media can aid plant diversity by giving rise to living plants from seeds and propagules (Wade 1989; Wade and Thompson 1993; Skousen et al. 2006; Showalter et al. 2010; Hall et al. 2010). Further, soil contains mycorrhizal fungi, important to plant growth and mine soil development (Miller and Jastrow 1992), along with organic nutrients and soil biota for nutrient cycling. Native forest soils have organic matter pools which can supply essential nutrients, including N and P, unlike raw spoils (Howard et al.. 1988; Li and Daniels 1994), and also increase soil water holding and cation exchange capacities.

As reviewed by Skousen et al. (2011), other research has found that weathered rocks, especially sandstones, produce excellent soil materials. Casselman et al. (2007) reported excellent tree growth on mine sites constructed from deep, uncompacted soil and weathered rock mixtures. Working on experimental plots in southwestern Virginia, Torbert et al. (1990) found weathered sandstone to support greater growth of pitch x loblolly hybrid pine than unweathered siltstone spoil materials. Studying native hardwoods on an active mine site in southern West Virginia, Emerson and others (2009) recorded more rapid growth on weathered than on unweathered sandstone materials (Figures 4-7). Working with four native hardwoods in eastern Kentucky, Angel et al. (2008) found that weathered sandstone spoils supported faster tree growth and more rapid colonization by native plants than either unweathered sandstones or a mixture of the two spoil materials.

Several studies found that soil properties occurring in soils and weathered spoils, including low soluble salts and moderately acidic pH, are associated with good growth by forest trees on coal surface mines (Torbert et al. 1988; Andrews et al. 1998; Rodrigue and Burger 2004; Jones et al. 2005; Showalter et al. 2007).

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Footnotes

1. SMCRA Sec. 515 (b) (2)
2. 30 CFR 816.22
3. Measured after mixing soil-sized fragments with deionized water at a 1:5 soil:water ratio, as per Rhoades (1982).
4. Crush raw spoils to <0.5 cm and mix with deionized water at a 1:1 ratio; allow the mix to sit for 30 minutes, then measure the water's conductivity after filtration.

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