



CHAPTER 3: SELECTING MATERIALS FOR MINE SOIL CONSTRUCTION WHEN ESTABLISHING FORESTS ON APPALACHIAN MINED LANDS

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INTRODUCTION

The Forestry Reclamation Approach (FRA), a method for reclaiming coal-mined land to forest (Chapter 2, this volume), is based on research, knowledge, and experience of forest soil scientists and reclamation practitioners. Step 1 of the FRA is to create a suitable rooting medium for good tree growth that is no less than 4 feet deep and consists of topsoil, weathered sandstone, or the best available material, or a combination of these materials. Selection and placement of a suitable growth medium are critical for successful reforestation on surface mines. Constructing mine soils using suitable materials enhances and accelerates development of diverse forest ecosystems. This Forest Reclamation Advisory provides guidance on how to execute Step 1 of the FRA and is intended for mine operators seeking to reestablish native forest as a postmining land use with pre-mining capability on 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 largely determined by the nature and properties of the soil.

The Appalachian Mountains are among the world's most ancient landscapes. The region's soils have developed over long time periods from the rocks that form this landscape, and they reflect the local climate, plants and animals, and landscape position (Jenny 1941). In turn, diverse plant communities throughout the Appalachians have evolved over millennia on these weathered rock and soil materials (Fig. 3-1).

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Figure 3-1.—A forest in the Appalachian Mountains. The Mixed Mesophytic Forest of the Appalachians is a diverse assemblage of more than 40 tree species that depend on native soil properties and other environmental factors. Photo by J. Burger, Virginia Tech, used with permission.

Weathering is the process of changing rocks into soil-like materials. During surface mining, unweathered rocks are often placed on the surface as a growth medium. 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 become established and grow in these presoil materials, producing organic matter to aid soil development and making the growth

medium 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. When starting with unweathered rocks, however, very long time periods are required to produce a soil that can support a plant community like the one that existed before mining (Fig. 3-2).

Although unweathered gray rock materials brought to the surface during mining will eventually weather into soils, they are generally not suitable for restoring pre-mining forest capability. Forest development can be accelerated by using the natural soil, weathered brown rock materials, or a combination, to reconstruct the land surface (Fig. 3-3). Salvaged soils and weathered rocks are superior to unweathered gray rocks as soil substitutes because they supply nutrients, air, and water to plants (Figs. 3-4 through 3-7). 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). (Please see the Appendix starting on p. A-1 for scientific names of species mentioned in this chapter.)



Figure 3-2.—Native soils of the Appalachian region (A) develop over long time periods and have properties that are well suited to supporting (B) native forest ecosystems. Photos by J. Burger, Virginia Tech, used with permission.



Figure 3-3.—Overburden consisting of weathered brown sandstone over unweathered gray sandstone and siltstone. The native soil has been stripped off the surface before blasting and mining. A native plant community is growing on native soils in the background. Photo by J. Skousen, West Virginia University, used with permission.



Figure 3-4.—Weathered brown sandstone on a West Virginia mine site 2 years after reclamation. The sandstone has formed a mine soil that supports good tree growth and promotes colonization by native plants. Mine soil pH is 6.0. The experimental areas on this mine site were not seeded with ground cover. Photo by J. Skousen, West Virginia University, used with permission.



Figure 3-5.—Unweathered gray sandstone on the same West Virginia mine site as in Figure 3-4 after 2 years showing some weathering into smaller particles, but generally poor tree growth and poor colonization by native plants. The pH is above 8.0. Photo by J. Skousen, West Virginia University, used with permission.



Figure 3-6.—The same mine site as in Figure 3-4, with weathered brown sandstone, 6 years after planting with native hardwood trees. Good growth by trees and herbaceous plants is evident. Photo by J. Skousen, West Virginia University, used with permission.



Figure 3-7.—The same mine site as in Figure 3-5, with unweathered gray sandstone, 6 years after planting with native hardwood trees. Although planted trees are surviving, growth is poor. Soil pH remains above 7.5. Photo by J. Skousen, West Virginia University, used with permission.

THE SURFACE MINING CONTROL AND RECLAMATION ACT

The federal Surface Mining Control and Reclamation Act of 1977 (SMCRA) 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 ...” (30 CFR Sec. 515 (b) (2)). The guidelines recommended here are consistent with SMCRA and promote the placement of soil materials that will create conditions suitable for forest reestablishment.

Forested land requires deep soil for productive tree growth (Andrews and others 1998, Torbert and others 1988). Regulations under SMCRA require 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 respreading only the upper few inches 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” (30 CFR 816.22). This Advisory provides guidance for practices that may be used to satisfy that requirement when restoring mined land as forest.

GUIDELINES

1. Salvage and respread soil (except where the operation would compromise machine operators’ 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 respreading 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—that is, generally 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 reestablishing forests. First, viable seeds and propagules contained in the soil (called a seedbank) enable restoration of native forest species (Hall and others 2010). Second, organic matter in the native soil contains nitrogen (N) and phosphorus (P), soil nutrients essential for plant growth that are not readily available to plants growing in unweathered mine spoils. Third, soil-dwelling animals and micro-organisms 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 respread immediately when possible to maintain living soil animals, micro-organisms, roots, and seeds. When soil is obtained from forested areas before mining, the salvage operation should take stumps, roots, and woody debris left on the site, transport them to the reclaimed area, and respread 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 or mixing salvaged soil with other overburden materials, or a combination of these measures, will aid reestablishment of a native forest plant community. It will also 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 (Chapter 6, this volume). However, a surface that is loose, is 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 (Fig. 3-8) or with the use of other equipment to level the surface (Fig. 3-9) (Chapter 4, this volume). 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.

2. Salvage and respread weathered spoil materials, and especially sandstones, where available and of suitable quality, to supplement soil materials

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

Weathered rocks are not suitable as a growth medium 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 less than 4.0, the soil 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 3-8.—Mixing of soil materials. Materials can be transported to the site, dumped in adjacent piles, and then lightly graded. Photo by J. Skousen, West Virginia University, used with permission.



Figure 3-9.—Excavator leveling dumped topsoil piles. An excavator can be used to level soil piles without causing compaction and can be useful when the dumped soil piles contain stumps, logs, and other coarse woody debris. Photo by J. Burger, Virginia Tech, used with permission.



Figure 3-10.—Weathered overburden above unweathered materials. Weathered overburden can be found immediately below the soil and often extends to about 30 feet beneath the surface—although it may be deeper. 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. Photo by C. Zipper, Virginia Tech, used with permission.

3. When soil and weathered brown sandstone are not available in adequate quantities, select unweathered overburden materials with suitable properties for use as supplemental materials

Just as a brown color can distinguish the weathering status of overburden, white and gray colors often indicate unweathered materials. Generally these materials when used alone will not support either rapid tree growth or rapid recolonization by native plants (Fig. 3-7) (Angel and others 2008, Emerson and others 2009). 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 medium may be unavoidable. In such cases, base selection of the best available material 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 between 4.5 and 7 will form a better growth medium for forest trees than other unweathered spoil 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 (Burger and others 2007, Conrad 2002). We have documented mine sites where soils composed of weathered overburden support tree growth comparable to unmined forests (see Box 3-1), 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 a growth medium for native forest trees

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

- a) Content of coarse fragments (larger than 2-mm-diameter particles) of greater than 60 percent

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).

- b) High pH (more than 7.5).
- c) Content of pyritic minerals sufficient to produce soils with pH less than 4, and to generate acids and excess salts, thereby elevating total dissolved solids (TDS) in runoff waters. Generally, materials with greater than 0.1 percent sulfur contents will be unsuitable.
- d) Minerals that will produce high levels of soluble salts. Selected materials should achieve electrical conductivities of less than 1,000 $\mu\text{S}/\text{cm}$, as measured by methods commonly applied in soil analysis¹, when trees are planted. Generally, raw spoils with electrical conductivities more than 1,000 $\mu\text{S}/\text{cm}$, as measured using a method applied to raw spoils², will be unsuitable.
- e) Carbonaceous rocks such as “black shales.” These rocks are usually unsuitable.

Avoid materials with these properties when constructing growth media for reforestation of coal surface mines. For a discussion of the scientific basis for these material selection guidelines, refer to Box 3-1.

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. This Advisory does not address material selection for reforestation on such sites.

¹Measured after mixing soil-sized fragments with deionized water at a 1:5 soil:water ratio, following Rhoades (1982).

²Crush raw spoils to less than 0.5 cm and mix with deionized water at a 1:1 ratio; allow the mixture to sit for 30 minutes, then measure the water’s conductivity after filtration.

Box 3-1. 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 Step 1 of the FRA—selecting and properly placing good soil materials—is critical for reestablishment of productive, diverse forests.

The native 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 (Hall and others 2010, Showalter and others 2010, Skousen and others 2006, Wade 1989, Wade and Thompson 1993). 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 and others 1988, Li and Daniels 1994), and also increase soil water-holding and cation exchange capacities.

As reviewed by Skousen and colleagues (2011), other research has found that weathered rocks, especially sandstones, produce excellent soil materials. Casselman and others (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 and others (1990) found weathered sandstone to support greater growth of pitch × 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 (Figs. 3-4 through 3-7). Working with four native hardwoods in eastern Kentucky, Angel and others (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 (Andrews and others 1998, Jones and others 2005, Rodrigue and Burger 2004, Showalter and others 2007, Torbert and others 1988).

SUMMARY

When native forest reestablishment is the postmining land use and reclamation goal, the FRA guidelines for creating a suitable rooting medium (Table 3-1) 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. 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 this region while protecting and restoring environmental quality. By following these guidelines, mine operators can help to restore productive and diverse native forests after mining.

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Table 3-1.—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 seedbank as well as soil-dwelling animals and micro-organisms	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) or (2), or a combination.
4. Unweathered rock to avoid	Has pyritic minerals, high pH, or high soluble salts, or a combination of these properties; 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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