Virginia Cooperative Extension

PUBLICATION 460-121

POWELL RIVER PROJECT

RECLAMATION GUIDELINES FOR SURFACE-MINED LAND

Creation and Management of Productive Minesoils

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Introduction

Since the 1940s, surface mining for coal in Southwest Virginia has disturbed more than 100,000 acres of land. Mining before the implementation of the federal Surface Mining Control and Reclamation Act (SMCRA) of 1977 and the resultant Virginia Permanent Regulatory Program of 1981 generated thousands of acres of surface-mined benches in Southwest Virginia — many with potential for more intensive future land uses. While the majority of these benches are relatively flat, use of these areas has been hindered by a number of problems, including poor soil productivity.

Since 1981, reclaimed mined lands have been returned to "approximate original contour" (AOC) and usually have more carefully constructed surfaces than older "prelaw" mining sites (figure 1). Today, the vast majority of surface mines in Virginia employ some form of controlled overburden placement techniques and utilize topsoil substitutes derived from blasted "minespoil" materials. This occurs because natural soils tend to be thin, rocky, acidic, and infertile over much of the Southwest Virginia coalfields, often making it impractical to salvage and respread topsoil on surface-mined areas. The plant species used in active reclamation must therefore be grown in minespoils composed of freshly blasted overburden materials. The properties of these minespoils are directly controlled by the physical and geochemical properties of the rock strata from which they are derived.

Once these minespoils are placed at a reclaimed surface and are utilized to support plant growth, we can consider them to be "minesoils." These two terms (minespoil vs. minesoil) will be used throughout this publication, but it is important to remember that spoils are blasted rock materials, while soils actually support plant growth, accumulate organic matter, and cycle nutrients over time. More information on basic soil science is available in Brady and Weil (2007).

Figure 1. A post-SMCRA reclaimed mine landscape with productive soils is able to support grazing cattle and is suitable for additional economically valued land uses.

In this publication, we will consider minesoil properties and management from two different perspectives: (1) the evaluation of minesoils on older, established mined lands; and (2) the creation of new minesoils on active mining areas through the selection and careful placement of spoil materials to generate productive topsoil substitutes. We use similar criteria and properties to evaluate both situations, although the two situations are very different from the reclamation manager's

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perspective. Older, existing minesoils (figure 2) must be evaluated and managed "as is" in the field, and the manipulation of their properties (particularly physical) may not be economically feasible. On an active mine, however, the reclamationist has the opportunity to custom build a set of minesoil physical and chemical properties specifically suited to the intended postmining land use.

Therefore, the first part of this publication deals with the description and understanding of minesoil properties as they exist after mining; the second part deals with the evaluation of geological, chemical, and physical properties of the various overburden rock strata commonly encountered in the Virginia coalfields and with the conversion of these minespoils into productive minesoils through the process of controlled overburden placement.

Geology and Spoil Characteristics

The strata disturbed by surface mining in Southwest Virginia are primarily Pennsylvania-aged sedimentary rocks derived from erosion of the Blue Ridge and the Ridge and Valley provinces hundreds of millions of years ago. The sediments were deposited in the margins of a shallow basin that supported lush swamp vegetation that accumulated in thick deposits, eventually forming coal beds.

The rocks found between the numerous coal seams in Southwest Virginia are predominantly sandstones, siltstones, and shales. This general classification is based on the primary grain size present in the rock. The individual sediment grains are cemented by iron (Fe), calcium carbonate, or silica, which "glue" the grains together into hard rocks. Iron sulfide, also known as pyrite (FeS_2), is also commonly found in the coal seams

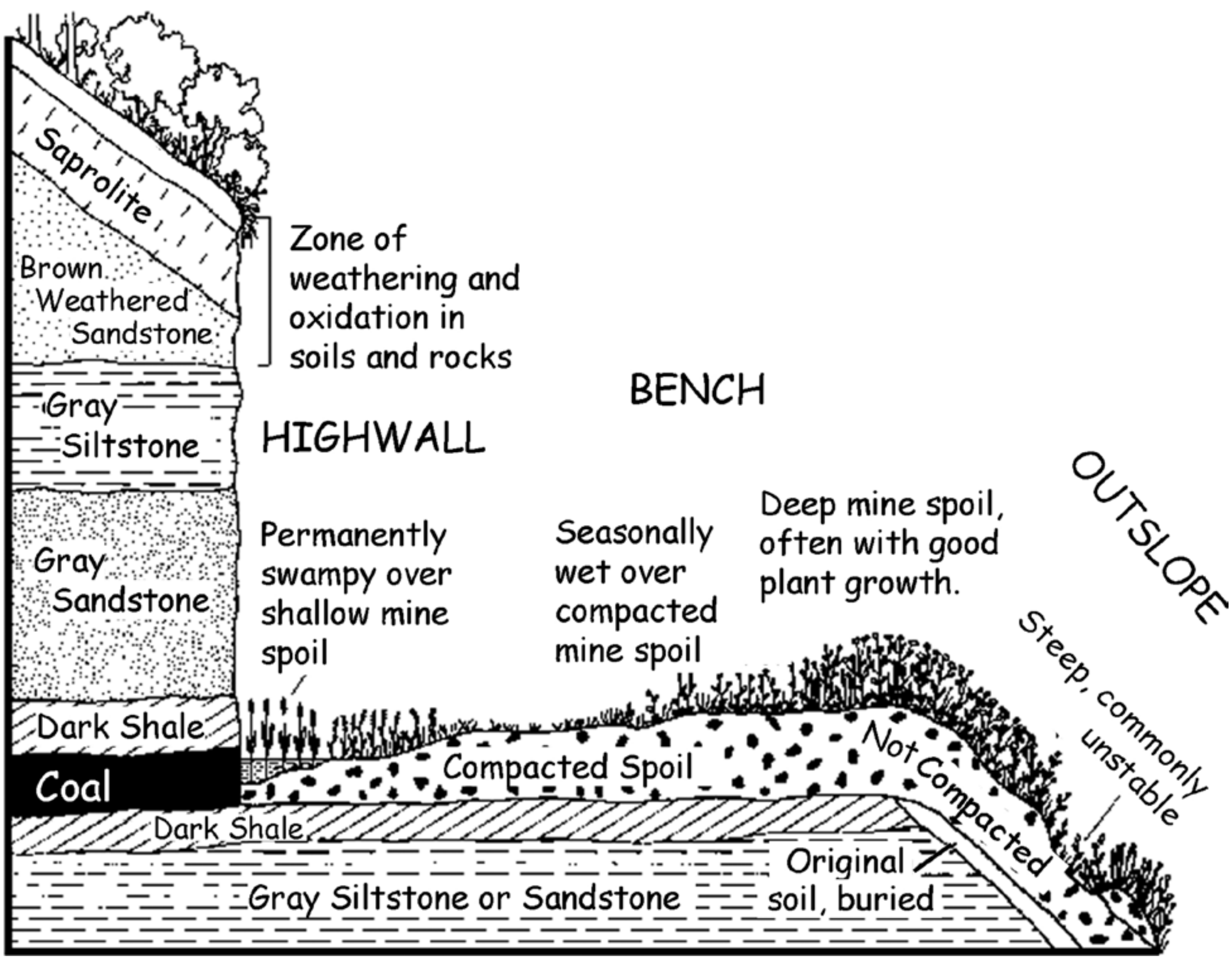


Figure 2. Typical highwall/bench/outslope topography generated by surface mining before the 1977 Surface Mining Control and Reclamation Act. Overburden removed from the mining cut was frequently bulldozed over the outslope, generating unstable slope conditions. Sandstones and siltstones dominate the geologic strata in Southwest Virginia, with shallow-lying rocks being oxidized and leached while deeper strata remain unweathered unless exposed by earth disturbances such as coal mining.

and occasionally in the rocks around the coal seams. As discussed later, the balance of acid-forming pyrites and base-forming carbonates is very important to spoil quality and potential environmental impacts. During mining, the rock strata above (overburden) and between (interburden) the coal seams are blasted into spoils that typically range from 10 to 25 percent fines (less than 2 mm or 0.1 inch). Rocks that originally resided immediately below the soil layer tend to be reddish-brown in color due to long-term weathering and oxidation reactions, while deeper unweathered rocks are typically gray to bluish-gray (figure 2).

Mine Soil Properties Important to Plant Growth

Chemical Properties

pH

Soil pH is a measure of active soil acidity and is the most commonly used and misused indicator of minesoil/spoil quality. The pH of a given minesoil can change rapidly as the rock fragments weather and oxidize. Pyritic minerals, when present, oxidize to sulfuric acid and drastically lower pH, while carbonate- ($Ca/MgCO_3$) bearing minerals and rocks tend to increase pH as they weather and dissolve. Unweathered (unoxidized) minesoils that contain significant amounts of pyritic sulfur in excess of their neutralizers (carbonates) will rapidly drop in pH upon exposure to water and oxygen. We have measured declines in pH from 8.0 to 3.0 in a matter of months in highly reactive acid-forming materials.

The reaction of weathered and leached minesoils is generally not subject to the rapid pH changes typical of fresh spoils; pH is therefore a relatively good indicator of quality in a weathered minesoil. In assessing soil pH, care must be taken to sample a number of different locations because the pH of minesoils may change drastically within several feet. [If you are not familiar with soil sampling procedures, consult with the local Virginia Cooperative Extension (VCE) office.] Attempts to revegetate minesoils with pH values below 4.0 should be avoided entirely, while minesoils with a pH between 4.0 and 5.5 will require significant addition of lime for optimal growth. A minesoil pH range of 6.0 to 7.5 is ideal for forages and other agronomic or horticultural uses. When the soil pH drops below 5.5, reduced legume and forage growth occurs due to metal [aluminum (Al), iron, magnesium (Mg)] toxicities, phosphorus (P) fixation, and reduced populations of nitrogen- (N) fixing bacteria.

However, some species of trees (such as pines) and other native plants can do quite well in soils with a pH between 4.0 and 5.5, while most native hardwood forest species prefer a pH in the 5.0 to 6.5 range (see VCE publication 460-123). A minesoil pH that is too high may also inhibit growth due to micronutrient deficiencies [manganese (Mn), zinc (Zn), iron] and phosphorus-fixation by carbonates. This is particularly true for most forest species, which are adapted to lower pH soils.

Soluble salts

Salts are inorganic chemical compounds that dissolve easily in water. Many of the sedimentary rock strata in Southwest Virginia weather to produce spoils that are relatively high in salts until leached by rainfall. These salts often include the sulfates of sodium (Na), calcium (Ca), magnesium, and potassium (K). The oxidation of pyritic spoils produces large quantities of soluble salts in addition to acidity, and it may take many years for such spoils to leach and stabilize.

High levels of soluble salts are toxic to plants and also inhibit nutrient and water uptake. Minesoils with water-extractable soluble-salt levels greater than 4 mmhos/cm (2,560 ppm on a soil test report) should be avoided, and salt-sensitive plant species may be affected at 2 mmhos/cm (1,280 ppm) or less. Soils with high levels of soluble salts tend to be sparsely vegetated or barren; may develop whitish, powdery deposits on the surface during dry weather; and may be associated with very low pH.

Soil fertility (nitrogen, phosphorus, potassium, calcium, magnesium)

All newly created minesoils and many older ones will require significant fertilizer element applications for the establishment and maintenance of any plant community. Minespoils are essentially devoid of nitrogen initially, so the total amount of nitrogen required to sustain plant growth over time must come from initial fertilization and subsequent symbiotic microbial nitrogen fixation by legumes. Usually, less than 150 pounds of nitrogen per acre are added as fertilizer when establishing nonforested, postmining land uses such as hayland/pasture, and much of this may be subject to leaching and gaseous losses. When establishing forested postmining land uses, lower nitrogen fertilization levels are advised (see VCE publication 460-124).

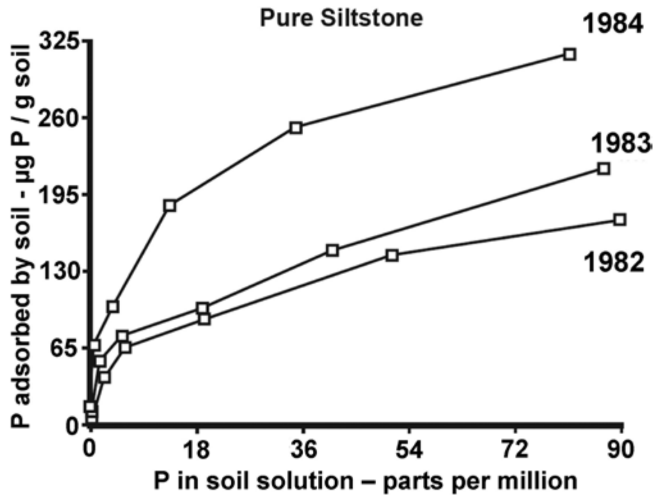
The vast majority of nitrogen needed to supply plant/soil community needs must therefore come from nitrogen fixation and subsequent mineralization of organically combined nitrogen. Thus, maintenance of a vigorous legume component within the plant community is critical for reclamation success. Most minesoils do not contain native populations of the essential nitrogen-fixing *Rhizobium* bacteria that enable legumes to capture atmospheric nitrogen, so care must be taken to carefully inoculate all legume seed used in new plantings.

Because nitrogen is primarily combined in organic matter in soils, the addition of organic amendments to the soil can greatly enhance total soil nitrogen and its availability over time. Biosolids (also known as sewage sludge) have been shown to be an effective minesoil amendment in numerous studies, but it may not always be available in sufficient quantities for use on remote sites. Local and state regulations and community attitudes frequently complicate the use of biosolids on disturbed lands.

Sawdust and bark mulch are also helpful in increasing the initial minesoil organic matter content but are generally low in nitrogen content. Therefore, use of these materials as soil amendments will also require heavy fertilization with nitrogen. Recently, yard waste composts and other fully stabilized organic materials have become increasingly available in most parts of Virginia and could play an important role in mined-land reclamation.

The maintenance of plant-available phosphorus in minesoils over time is hindered by two factors: (1) fresh minespoils are generally low in readily plant-available (water-soluble) phosphorus; and (2) as minesoils weather and oxidize, they become enriched in iron oxides that adsorb water-soluble phosphorus, which is then "fixed" into unavailable forms. The tendency of minesoils to fix phosphorus increases over time (figure 3). Because organic-bound phosphorus is not subject to phosphorus-fixation, it is critical to establish and build an organic phosphorus reservoir in the soil to supply long-term plant needs through phosphorus mineralization. Large fertilizer applications of phosphorus during reclamation will ensure that sufficient phosphorus will be available over the first several years to support plant growth and to build the organic phosphorus pool.

Some phosphorus will also become available to the plant community as native calcium phosphates in the rocks decompose, but this phosphorus is not sufficient to meet the needs of a vigorous plant community. Many plant species, particularly those that are mycorrhizal (e.g., *Sericea lespedeza* and most native trees), are able to draw phosphorus from sources with difficult availability.



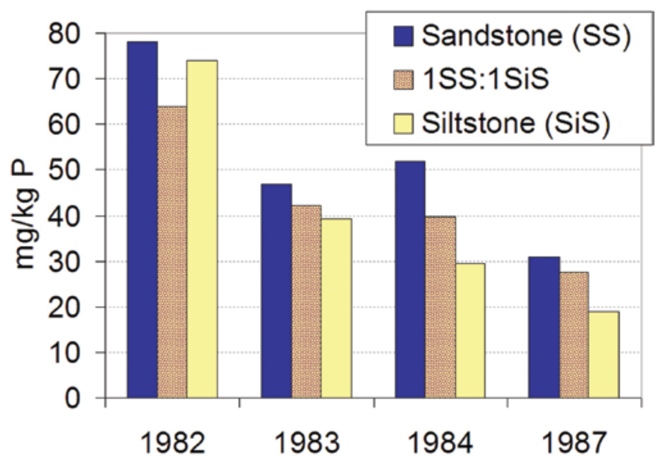


Figure 3.

Upper, Phosphorus adsorption isotherms for a Southwest Virginia minesoil over three growing seasons. The isotherms indicate that as the concentration of phosphorus in solution increases, the amount of phosphorus adsorbed on the rock and soil particle surfaces (fixed) increases. The consistent increase in phosphorus fixation over time is due to the formation of iron oxide coatings in the soil as it weathers and indicates that long-term phosphorus availability can be a problem if not managed correctly.

Lower, Bicarbonate-extractable phosphorus, an indicator of plant-available phosphorus, decreased steadily over five years, with time for the siltstone material represented by the upper figure, sandstone, and a siltstone-sandstone mix, illustrating how the concept represented by the upper chart influences nutrient availability to plants growing in minespoils.

With adequate fertilization and liming, the fertility needs of newly established vegetative covers can easily be met on almost any mined site. However, while vegetation establishment is certainly an important first step, the SMCRA requires that a vigorous plant community persist for at least five years on newly mined sites. This can be difficult when fertilizer and lime augmentation are not allowed by the designated land use practices. Initial fertilization effects will usually last for the first two growing seasons, assuming good initial establishment. After that time, steady decreases in standing biomass and groundcover are common, even on the best of minesoils (figure 4).

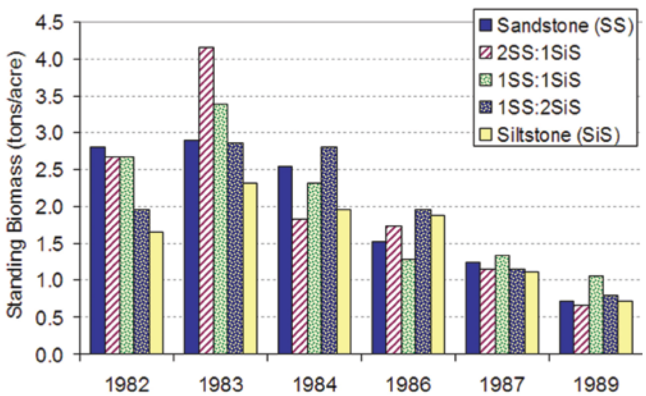


Figure 4. Standing biomass of tall fescue on a Southwest Virginia minesoil experiment over time (Haering et al. 1990). Note that the second year yields were highest for all rock types and then declined with time. This is typical of fertilized minesoil systems, particularly when a vigorous legume component is not successfully established. Also note the pronounced effect of rock type on yield, especially in the early years.

Assuming adequate initial minesoil conditions, the long-term productivity of the plant/soil system is dependent upon several major factors: (1) the accumulation of soil organic matter and nitrogen, (2) maintaining nitrogen-fixing legumes in the stand, and (3) establishment of an organic phosphorus pool and the avoidance of phosphorus fixation. Both of these are, in turn, highly dependent on the introduction and function of microbial communities over time. On most newly reclaimed soils, it is likely that nitrogen will first limit plant growth due to greater plant needs and that phosphorus fixation will become a problem in later seasons as the minesoils weather.

However, if plant production in the first few years is limited by nitrogen, the transfer of fertilizer phosphorus into organic forms will be limited, thus increasing phosphorus fixation losses. Similarly, low soil phosphorus levels may also hinder nitrogen accumulation, because symbiotic nitrogen-fixing bacteria have a high phosphorus demand. Therefore, the development of a minesoil organic matter pool is essential to long-term fertility; minesoil nitrogen and phosphorus must be managed together — not as independent factors.

Physical Properties

Rock content

The majority of plant-available water in soils is held in soil pores formed by particles less than 2 mm (0.1 inch) in size. Any particles larger than 2 mm are referred to as “rock fragments.” Soils high in rock fragments have larger pores that cannot hold enough plant-available water against leaching to sustain vigorous growth over the summer months.

Minesoil rock fragment contents vary — from less than 30 percent to more than 70 percent — due to differences in rock hardness, blasting techniques, and spoil handling. The rock content in the surface of a reclaimed bench or outslope will decrease over time due to weathering of rock fragments to soil-sized particles. Topsoil materials, when they can be salvaged, are typically much lower in rock content than spoils, and therefore have better water-retention characteristics. Similarly, rock spoils derived from the upper weathered and oxidized sections of the overburden column (see figure 2) usually generate a spoil with fewer rock fragments than deeper, harder, unweathered strata.

Soil texture

Soil-sized particles are smaller than 2 mm and are responsible for the majority of water-and nutrient-holding capacity in minesoils. The relative amounts of sand-size (2.00 to .05 mm), silt-size (.050 to .002 mm), and clay-size (less than .002 mm) particles determine soil texture. Minesoils with sandy textures cannot hold as much water or nutrients as finer-textured soils like loams and silts. The finer-textured soils (e.g., silts) have a tendency to form surface crusts, often contain high levels of soluble salts, and have a poor “tilth” or consistence. The particle-size distribution of the soils with loamy textures is generally ideal. The particle-size distribution of minesoils is directly inherited from their parent rocks or spoils (as discussed later), and it is typically sandy loam to loam in Southwest Virginia. Silt loam textures are also common where spoils are dominated by siltstones.

Bulk density, compaction, and available rooting depth

The bulk density of productive natural soils generally ranges from 1.1 to 1.5 g/cm^3. Many minesoils in Southwest Virginia are highly compacted (bulk density more than 1.7 g/cm^3) within several feet of the surface due to heavy machinery traffic (figure 5). Soil compaction directly limits plant growth, because most species are unable to extend roots effectively through high bulk-density minesoils.

In a study of older minesoils (five to 20 years) in the Powell River Project watershed, we found that compaction was the major soil factor limiting long-term revegetation success (Daniels and Amos 1981). Virginia Tech foresters have also found that compaction limits tree growth and survival on reclaimed mine sites (see VCE publication 460-123). Severely compacted (bulk density more than 1.7 g/cm^3) minesoils — particularly those with less than 2 feet of effective rooting depth — simply cannot hold enough plant-available water to sustain vigorous plant communities through protracted drought.

Compacted zones may also perch water tables during wet weather conditions, causing saturation and anaerobic conditions within the rooting zone. Compacted zones result from the repeated traffic of rubber-tired loaders and haulers, and, to a lesser extent, bulldozers. Although mine regulatory agencies today advocate reclamation practices that avoid or limit soil compaction by heavy machinery, this was not the case in past years. As a result, many southwestern Virginia minesoils suffer from soil compaction effects.

In order to hold enough water to sustain plants through prolonged droughts, 3 to 4 feet of loose, noncompacted soil material is required. Shallow intact bedrock, the presence of large boulders in the soil, and heavy compaction commonly limit rooting depth in minesoils. The only definitive way to determine rooting depth in an older minesoil is to dig backhoe pits and actually measure it. The presence of rock outcrops or extreme stoniness can be used as a general indicator of rooting volume. On older mined lands, the depth of spoil above bedrock can often be discerned by looking at the point where the bench meets the outslope. The soil depth at this point may not reflect that of the entire area, however. The presence of wet, swampy areas on a bench usually indicates shallow rock or compacted zones. Overall, when poor plant growth is encountered in soils with otherwise suitable physical and chemical properties, insufficient rooting depth is probably the cause.

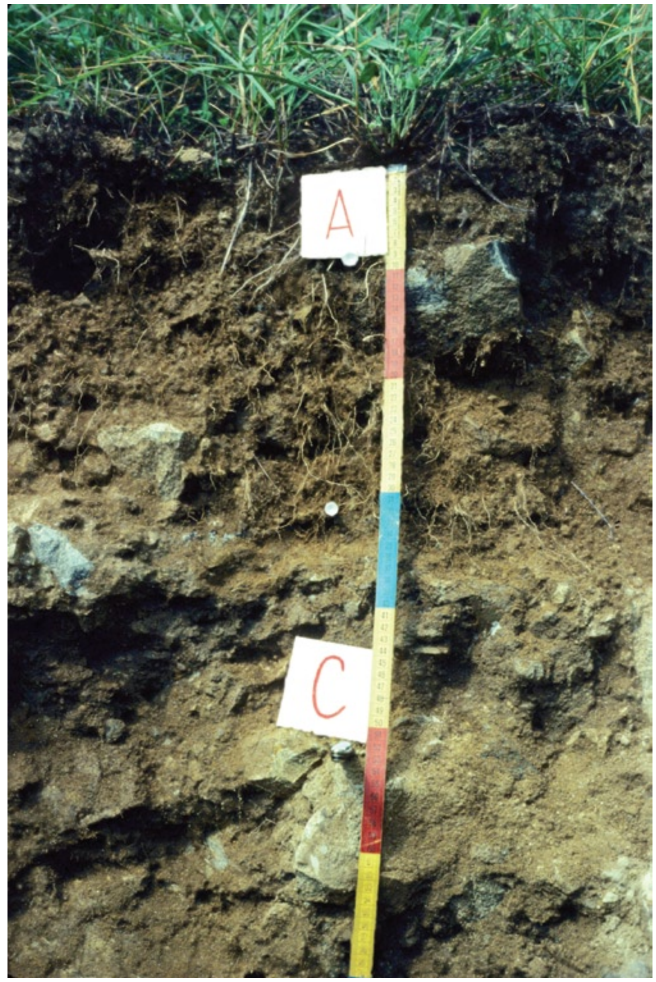


Figure 5. Highly compacted minesoils, such as those which occurred commonly in Southwest Virginia during the 1960s, ’70s, and ’80s and continue to occur occasionally today. Note that root density is high in the upper 30 cm (about 1 foot, which occurs between the “A” and the “C” markers), but visible roots have failed to penetrate soil material below that depth. This mine site had been compacted by equipment operation and then covered with the foot of loose material occupied by the roots that are visible in this photograph. The subsurface compaction in this otherwise suitable minespoil material strongly limits rooting depth and water-holding capacity. Fortunately, the surface layer is relatively loose, but in some instances, minesoils are compacted all the way to the surface. Heavily compacted soils are usually barren. In our studies of older minesoils, we have seen compaction effects that limit rooting for decades after the mining and reclamation operations were completed.

Slope and topography

Minesoils with slopes greater than 15 percent are generally unsuitable for intensive land uses such as vegetable or crop production, but they may be suitable for grazing and reforestation. Broad flat benches — including those that occur on pre-1977 mined lands — and fills with slopes less that 2 percent often have seasonal wetness problems. Many benches with an overall gentle slope contain areas of extreme rockiness, pits, hummocks, and ditches. Many of these features can only be discerned by walking over the area. The average slope of most reclaimed modern mines (post-1977) is quite a bit steeper than the older benches, but the newer landforms are considerably smoother and more uniform in final grade.

Stability

On older mined lands (figure 2), bench areas directly above intact bedrock are usually fairly stable but may be subject to slumping — especially when near the edge of the outslope. Tension cracks running roughly parallel to the outslope indicate that an area is unstable and likely to slump. Areas perched above outslopes with slopes greater than 30 degrees should also be avoided, even if tension cracks are not present. In general, landforms created since 1977 are more stable than those created earlier because spoils are no longer allowed to be placed over the outslope. However, many approximate original contour backfills in the region are still extremely steep.

Minespoil/soil color

The color of a minespoil or weathered minesoil can tell us much about its weathering history, chemical properties, and physical makeup. Bright red, yellow, and brown colors in spoils and soils generally indicate that the material has been oxidized and leached to some degree. These materials tend to be lower in pH and free salts, less fertile, low in pyrites, and more susceptible to physical weathering than darker-colored materials. Gray colors in rocks, spoils, and soils usually indicate a lack of oxidation and leaching, and these materials tend to be higher in pH and fertility. Very dark gray and black rocks, spoils, and minesoils contain significant amounts of organic materials and are often quite acidic. Dark colored spoils are also difficult to revegetate during the summer months because they absorb a great deal of solar energy and become quite hot.

Sampling and Analyzing Minesoil Properties

In all of the parameters discussed above, minesoils vary tremendously from point to point on any mined site. A fair amount of accuracy in sampling and characterizing the minesoils of a given area can be achieved, however, by carefully surveying the area and then sampling and evaluating each area of contrasting vegetation, slope, rock type, and stoniness. All of these field soil properties are certainly not important to all potential land uses, but together, they will indicate overall site quality for a variety of uses. Minesoil samples should be taken from uniform areas of rock type wherever possible, and we recommend a minimum sampling intensity of one composite soil sample per 10 acres of mined land.

Once an appropriate minesoil sample has been taken, it should be submitted to a qualified soil testing laboratory for chemical analysis. It is important to indicate that the sample is from a mined land area rather than from a natural soil; this will alert the laboratory that the sample may not react as expected to some of the tests. At the Virginia Tech Soil Testing Laboratory, proper labeling will ensure that appropriate lime and fertilizer recommendations are made. At a minimum, the sample should be analyzed for pH, soluble salts, and extractable nutrients (phosphorus, calcium, magnesium, potassium). Fresh minesoils contain large amounts of readily oxidizable iron, manganese, and/or carbonates that interfere with the determination of organic matter by common soil analysis techniques, so do not request this test unless the materials have been thoroughly weathered.

Minesoil pH and Liming Recommendations

If the soil pH of a weathered minesoil is less than 4.0 and the soluble salts are high, you can be reasonably certain that the soil contains reactive pyrites, and acid-base accounting should also be performed as discussed in the next section to determine the appropriate liming rate. If the minesoil has been exposed at the land surface for a sufficient period of time for pyrite oxidation effects to become apparent (if sulfides are present — up to two years), you can assume that the pH, soluble salt, and liming recommendation values given on your soil test are reasonably accurate. If the minesoil material is less than several years old, the full extent of pyrite oxidation might not be evident (e.g., low pH), and acid-base accounting should be performed to accurately estimate liming needs.

In general, minesoils are fairly coarse-textured and low in buffering capacity, so applications of agricultural lime at 1 to 5 tons per acre (depending on initial pH) are usually sufficient to achieve a target pH of 6.5 for typical hayland/pasture forages. Forest species, particularly pines, thrive at lower pH levels, however, and liming is generally not needed unless pyrites are present (see VCE publication 460-123).

Extractable Nutrients and Fertilizer Recommendations

Unfortunately, extractable levels of phosphorus, calcium, magnesium, and potassium for most soil tests have never been correlated with actual plant uptake and performance on Southwest Virginia minesoils. This fact, coupled with the extreme variability in rock type and mineral solubility found in minesoils, makes it very difficult to make accurate fertilizer recommendations. When phosphorus, calcium, and magnesium levels are in the low range for a given soil test, you can assume that the spoil material has been extensively weathered and leached, and that lime and fertilizer applications will likely be needed for optimal plant production. On the other hand, unless minesoils are well-weathered and are under active fertility management, very high values of phosphorus, calcium, and magnesium **should not** be interpreted as being plant-available, because many soil testing extracts (particularly those employing acids) actually dissolve these elements out of solid mineral phases that are not plant-available over the short term. Potassium is found in very high levels in fresh minespoils but is also subject to long-term leaching losses. For these reasons, we do not believe that fertilizer recommendations can be fine-tuned to a given site and its vegetative cover based on conventional soil testing approaches.

We recommend that at least 110 pounds per acre P (equivalent to 250 pounds per acre of P_2O_5, as expressed by the fertilizer grade) and 55 pounds per acre K (100 pounds per acre of K_2O, as expressed by the fertilizer grade) be applied to new seedings or as supplements to existing forage stands. The nitrogen application rate for new seedings should not exceed 150 pounds per acre to avoid suppression of legumes, but at least 75 pounds per acre is required to support the establishment of annual and perennial grasses. Established forage stands with a vigorous legume component will require little if any nitrogen fertilization.

These recommendations are given as a general minimum for conventional establishment of erosion-control mixtures or the maintenance of hayland and pasture covers. Establishing vegetative cover for forestland use is covered in VCE publication 460-124.

Overburden Analysis for Topsoil Substitute Selection

The first step in this process is to obtain accurate overburden analysis samples prior to mining. Each major stratum should be sampled from drill cuttings at several locations, and care should be taken to avoid contaminating the samples with drilling greases. Each overburden sample should be characterized for rock type, texture, and thickness of host stratum. Ground samples of each stratum should be analyzed by a competent laboratory for pH, acid-base accounting, phosphorus, potassium, calcium, magnesium, and soluble salts.

From a chemical standpoint, the acid-base accounting procedure, which balances acidity (from pyrites) against total alkalinity (from carbonates), is probably the best indicator of spoil quality. Greater detail on acid-base accounting fundamentals is given in VCE publication 460-131. Conventional acid-base accounting measures the total sulfur content of a sample and assumes that all of it will oxidize to form sulfuric acid. Similarly, the total neutralization capacity of carbonates in the sample is measured and assumed to be fully reactive. In the absence of carbonates and assuming complete reaction, 1 percent total pyritic sulfur in a spoil will generate enough acidity to require 32 tons of agricultural lime addition per thousand tons of spoil to achieve pH 7.0 conditions. Because average minesoil weighs approximately 1,000 tons per acre in its upper 6 inches of soil depth, the "potential acidity" value corresponds to the predicted per-acre liming requirement for a given spoil or minesoil.

Negative values for potential acidity indicate a lime demand for a given material, while positive values indicate that the sample contains an excess of neutralizers, typically from carbonates. The conventional acid-base accounting method described here is subject to a number of potential sources of error that are beyond the scope of this discussion, but it is a fairly reliable and readily available analysis that generates consistent liming prescriptions.

Overburden strata that are net alkaline should weather to produce minesoils with pH levels more than 5.5, which are quite suitable for plant growth following nitrogen, phosphorus, and potassium fertilization. Overburden strata with net acidity levels below negative two to three parts per thousand should be avoided; strata with net acidities below negative five parts per thousand are required by law to be handled as potentially toxic materials.

As mentioned earlier, pH is a measure of active soil acidity and is often a poor predictor of spoil quality. While pH can be used as a rough indicator, there is no substitute for accurate acid-base accounting. Spoils high in soluble salts (more than 2,560 ppm or 4 mmhos/cm) should be avoided as well. A salty spoil that does not contain pyritic materials will rapidly lose its salts to leaching in the field, however, and might be suitable as topsoil substitute material once this occurs. The discussion of extractable nutrients and fertilizer recommendations presented earlier also applies to premining overburden analysis. In particular, extractable phosphorus, calcium, magnesium, and potassium levels from fresh, unweathered spoils are typically quite high and cannot be assumed to be plant-available; therefore, they should not be used as criteria for selecting topsoil substitute materials.

Controlled Overburden Placement

Use of Natural Topsoils vs. Topsoil Substitutes

Certain geologic strata can be designated for use as topsoil substitutes when it can be shown through premining sampling and testing that their physical and chemical properties surpass those of the native soil (where present) for potential plant growth. However, if sufficient quantities of productive natural soils are present on a site, they should be used as the surface medium whenever possible. While the majority of native soils in these premining Appalachian landscapes are relatively shallow and infertile, occasional deeper soil bodies do occur, particularly in coves and on stable ridgetops.

If it is practical to isolate and store sufficient quantities of these materials so that final surface coverage of the site will exceed 24 inches, there are great advantages to the use of natural soils. The organic matter and microbial populations of natural soils are invaluable to the revegetation process. Regardless of the quality of the natural soil, however, it must be present in large enough quantities to allow sufficient thickness on the final reclamation surface. Quite frequently, only 6 to 18 inches of natural soil are spread over highly compacted spoil materials, leading to rooting restrictions and problems of seasonal wetness.

It is also important that the true topsoil ("A" horizon plus "E" horizon) be separated from the underlying soil and rock horizons during stripping and then either spread immediately or stored properly to maintain the viability of aerobic microbial populations. Due to the thin nature of most of the surface soil horizons in southwestern Virginia's coalfields, when natural topsoils are employed in reclamation, they are usually a mixture of all soil horizons above hard bedrock. Thus, the positive influences of their organic matter and microbial content are considerably reduced.

Some mining operators do find it beneficial, however, to mix whatever true topsoil becomes available with their designated topsoil substitutes during final reclamation grading. The benefits of this practice include inoculation with beneficial soil microbes, a source of slow-release (organic) nitrogen and phosphorus, and physical properties that are more favorable as a seedbed than raw spoil.

Selecting Geologic Materials for Use as Topsoil Substitutes

The rock beds in the Southwest Virginia coalfields lie essentially flat with a gentle dip to the northwest. The coal seams are separated by varying thicknesses of sandstones and siltstones, with a minor component of shales, as discussed earlier. Commonly, multiple seams of coal are mined, with all strata above the lower seam being blasted into spoils and handled in some fashion during mining. In order for these hard rock spoils to be successfully employed as topsoil substitutes, the optimal strata must be identified before mining so the mining plan can be designed to place the proper stratum at the final reclaimed surface. Also, any potentially toxic strata must be identified and then isolated away from the surface and local groundwater. Before mining, the thickness and variability of the various overburden strata are determined by exploratory drilling. All major strata are tested unless previous experience indicates that one particular stratum is a superior topsoil substitute material.

In general, the following criteria (see table 1), in order of importance, are essential to evaluate the suitability of a given strata for use as a topsoil substitute: (1) acid-base accounting, (2) rock type, (3) extractable nutrients, (4) pH, (5) soluble salts, and (6) degree of weathering and oxidation before mining. Ideally, a stratum or multiple strata are isolated, which will be nonacid-forming over time, and therefore, high in pH and low in soluble salts. Rocks low in acid-forming pyrites (FeS_2) and high in carbonate cementing agents are ideal. Rock type is important because spoils derived entirely from sandstones tend to be very coarse and droughty, while

Table 1. Topsoil substitute selection criteria for Southwest Virginia. Criteria are listed in order of importance.

Criteria	Explanation
Potential acidity	Determined by acid-base accounting by competent lab. Should be net neutral or better (zero to positive values). Materials with values less than −5 tons per thousand $CaCO_3$ requirement must be avoided.
Rock type	Mixtures of sandstones and siltstones/shales are superior to unmixed spoils. Avoid pure, fine siltstones and shales when possible.
Extractable nutrients	Useful for general comparisons among candidate materials but cannot be literally interpreted in terms of plant availability or for fertilizer recommendations.
pH	Not reliable as a predictor of the long-term soil quality for unweathered minespoils. Values less than 4.0 indicate that pyrite oxidation has occurred.
Soluble salts	Avoid when more than 4 mmhos/cm (or 2,560 ppm). Many pasture legumes and other salt-sensitive crops will be affected at much lower values (less than 1,280 ppm). Generally not a problem as long as acid-forming materials are avoided.
Weathering	Brown oxidized strata will blast to finer spoils with higher water- and nutrient-holding capacities. However, oxidized strata will be lower in pH and extractable nutrients (phosphorus, calcium, magnesium, potassium).
Thickness	Any designated topsoil substitute strata must be present in sufficient thickness and location within the overburden section to be economically isolated and hauled by the active mining operation.

those derived entirely from fine siltstones and shales tend to form hard surface crusts and impede water percolation.

We have found that mixtures of rock types are superior to those composed of all siltstone or sandstone, but the differences attributable to rock type diminish with time (see figure 4). As mentioned earlier, extractable nutrient tests are fairly unreliable when used with fresh spoils or young minesoils, but they can be used to compare among potential substitutes in a relative sense.

In weathered, near-surface strata, materials with a pH below 5.0 should generally be avoided unless a return to forest vegetation is anticipated. Quite often, mining operators prefer these leached and oxidized strata for use as topsoil substitutes because they blast into a finer, less-rocky spoil that is easily handled and spread. These brownish-red oxidized materials are usually high in iron oxides, however, which can be detrimental to long-term phosphorus availability due to their phosphorus-fixing capacity (see figure 3).

Another advantage to using the finer, preweathered strata is that they will hold more plant-available water due to their lower rock content. Brown, oxidized, sandy spoils may be a good topsoil substitute choice for establishing forest vegetation (VCE publication 460-123), but other spoil types will often be superior for hayland/pasture and other land uses. The majority of unweathered strata blast into spoils that contain 20 to 40 percent soil-size fragments (less than 2 mm) and will supply sufficient plant-available water as long as they are placed at the final surface with sufficient uncompacted depth.

Perhaps the most important criteria for selecting a topsoil substitute is whether or not the designated strata can be isolated and handled within the mining plan without excessive cost to the operator. If an ideal stratum is thinner than the usual blasting lift thickness or placed inopportunely within the geologic column, its use may be impossible. Quite often, two or more adjacent strata within the same blasting lift will be identified as the substitute materials and then handled and spread together. In this fashion, strata with dissimilar physical and chemical properties can be mixed together into a composite with properties more favorable than those of individual stratum.

Minesoil Construction to Ensure Reclamation Success

Before the enactment of SMCRA, little thought was given to selective handling of overburden. The final surface generated for revegetation was usually a rough-graded mixture of all strata present in the overburden column, leading to extreme heterogeneity in minesoil properties on these older benches. It is not uncommon in these areas to find 3.0 and 8.0 pH minesoils directly adjacent to one another. This spoil variability, combined with problems of severe compaction, makes it difficult to develop uniform management strategies for many of these older benches. The primary objective of modern controlled overburden placement techniques is to place a designated topsoil substitute of controlled geologic origin at the final reclamation surface. This final lift of spoil must be placed with sufficient thickness (at least 3 to 4 feet) to support vigorous plant growth over time and must not be excessively compacted.

Continuous on-site coordination and supervision by the mining operator or job foreman is necessary to ensure that the designated strata are correctly isolated and hauled to the final reclamation surface. First, the reclamation area is filled with nonselected spoil to a level 4 to 5 feet below the planned final surface and rough-graded. Then, the entire area is end-dumped with the appropriate spoil in closely spaced piles. The spoil may remain in this configuration indefinitely before the final reclamation grading is performed in one operation (figure 6).

Figure 6. Final reclamation grading of a topsoil substitute. The designated material has been end-dumped in closely spaced piles and is being graded with a small bulldozer. By following the set of practices outlined in this chapter and excluding traffic after final grading, 3 to 4 feet of loose, uncompacted minesoil material can be created in most surface mining environments.

Grading should be delayed until just before seeding whenever possible to prevent surface crusts from forming. This will also minimize surface runoff and erosion. Grading wet spoils promotes compaction and should be avoided whenever possible. Overall grading activities should be limited to the minimum required to achieve the prescribed landform. Excessive grading and "tracking in" practices should be avoided at all costs to minimize soil compaction and maximize local soil infiltration capacity.

By following these procedures, thick, uniform, uncompacted minesoils can be produced with few direct costs to the operator (other than those involved with coordination and supervision), because all of the materials must be handled and moved regardless of placement location. Throughout the process, it is important to maintain alternate spoil dumpsites so that spoils unsuitable for topsoil substitute use are eliminated from the final surface. The key factor is control of overburden handling and movement for the sake of improved reclamation success.

Careful coordination of the entire surface mining operation is required for a designated topsoil substitute strata to actually become a part of the final reclaimed surface. Failure to actively control the placement of overburden materials results in variable soil properties because a number of different rock strata make up the final surface. While this may not be a problem when all of the strata are suitable for plant growth, patches of highly acidic or high-salt spoils at the surface may decrease the percentage of vegetative cover enough to prevent bond release. Severe compaction of otherwise suitable spoils will also greatly decrease the density of vegetation.

In summary, we recommend that the following overburden selection and placement procedures be followed:

1. **Select the best substitute overburden strata**, basing your judgment on the following parameters: acid-base balance, pH, soluble-salt content, rock type, and overall thickness. Other parameters such as calcium, magnesium, potassium, and phosphorus should enter into the decision but are not as critical.

2. **Coordinate the surface mining operations** so that the designated strata are separated and hauled to the proper areas for final grading. Exclude excessively stony (more than 80 percent rock fragments) spoils.

3. **End-dump the entire final surface** using only the designated spoil, with enough spoil to ensure

a minimum thickness of 4 feet over any adverse underlying materials.

4. **Grade the final surface** with a bulldozer, leaving at least a 2 percent grade for drainage of surface water. Exclude all machinery from the area after grading to avoid excessive compaction.

5. **Seed and/or mulch the site immediately**, when possible, to avoid the formation of surface crusts and begin the development of a soil nutrient and organic matter pool.

Summary

Existing minesoils tend to be quite variable in the field, but they can be managed effectively once their chemical and physical properties have been correctly determined. Compaction, low water-holding capacity, and associated rooting restrictions are the major factors limiting the productivity of minesoils in this region. High levels of potential acidity seriously restrict the productivity of some minesoils, but this problem is much more limited in extent than minesoil compaction. Soil testing procedures are useful for comparing overburden materials for use as minesoils, but they cannot be interpreted with the same degree of accuracy as natural soils.

Productive topsoil substitutes can be generated from hard rock overburden in Southwest Virginia, but care must be taken in spoil selection and placement. It is particularly important to reclamation success that controlled overburden placement techniques be used to generate at least 4 feet of loose spoil at the final surface for seeding. The accumulation of soil organic matter and organically complexed nitrogen and phosphorus over time, the maintenance of nitrogen-fixing legumes in the vegetation, and the minimization of phosphorus fixation by soil iron oxides are important factors that control the long-term productivity of minesoils.

Minesoils carefully constructed from topsoil substitute overburden materials can be more productive than many of the Appalachian region's natural soils.

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