various topsoiling and vegetational situations. In general, outslopes, faces, buttresses, diversions, and exit channels should be vegetated to control erosion and maintain stability. In the case of prelaw portions of structures, the inspector should consider the effectiveness of the existing vegetative cover on controlling erosion. Where prelaw portions of mines are used to facilitate postlaw surface coal mining and reclamation operations, it is generally accepted that those areas must meet applicable performance standards. As with coal processing facilities, the specific treatment, topsoiling, and revegetation requirement may vary by plan and program.

There are situations where topsoil removal as a primary surface coal-mining and reclamation operation has been waived. Where other reclamation methods have been approved in the PAP such as the substitution of mixed overburden, the inspector should carefully review the substitution analysis and requirements in the PAP and note field deficiencies where the plan is implemented properly. Where the plan is not properly carried out, the inspector usually will need to correct the situation as required by his or her approved program.

OVERBURDEN CHARACTERISTICS

A detailed examination of the soils and geologic strata above the coal seams before surface mining of any permit area is needed for use in 1) developing a soil reconstruction plan, 2) evaluating the success of reconstruction, and 3) determining amendments and species for revegetation.

Soil Properties

The chemical, physical, and biological properties of a soil determine the suitability of that soil as a medium for plant growth. Ideally, the objective of soil reconstruction is to replace and restore a plant-growth medium that has characteristics similar to and is at least equally suited for plant growth and production as the soils that were in place before mining. In some situations it may be possible to reconstruct a growth medium with properties superior to those before mining. A knowledge of soil and overburden properties or characteristics can help the operator and inspector identify those materials most suitable for replacement as plant-growth media. Similarly, this knowledge can be helpful in identifying materials with properties that limit or prevent plant growth and that should be avoided or, where necessary, amended.

Chemical Properties

The chemical properties of minesoils most often of concern in revegetating mined lands are chemical reaction (pH), toxic concentration of certain elements, and deficiencies of essential elements (nutrients).

Soil Reaction (Acidity and Alkalinity)

Soil reaction is the degree of acidity or alkalinity, usually expressed as pH. It is a measure of hydrogen-ion activity in solution, expressed on a scale of 0 to 14. A pH of 7.0 is neutral. The lower values indicate acidity and the higher values alkalinity. The pH scale is logarithmic. The intensity of acidity and alkalinity changes tenfold for each unit change in pH. For example, a pH of 4.0 is 100 times more acid than a pH of 6.0.

Soil reaction (pH) is a useful criterion for predicting and defining many of the problems associated with the revegetation of surface-mined land. Not only is plant growth affected by pH, but inferences can also be made about other qualities of soil. For example, the availability of some nutrients to plants is limited in strongly acid, extremely acid, strongly alkaline, and very strongly alkaline soils, but these nutrients are readily available to plants in soils that are moderately acid to slightly alkaline.

Some plant species are more tolerant than others of acid or alkaline soil conditions. Using acid-tolerant or alkaline-tolerant species in revegetating minesoils may in some situations be more practical than applying soil amendments. However, in many cases, acidic and alkaline soils will have to be amended if the areas are to be revegetated satisfactorily.

Oxidation of iron sulfides is the most common cause of extremely acid soil conditions. Attempts to revegetate these materials will have limited success unless amendments are used to raise the pH to at least 5.5 because most species will grow where soils have pH levels of 5.5 or higher. Some species will tolerate strongly acid (pH 5.1 to 5.5) and very strongly acid (pH 4.5 to 5.0) soil conditions. Few species will survive or grow well in extremely acid (pH < 4.5) soils. These limits will vary depending on the overall chemical and physical characteristics of soils and geologic strata. *Eragrostis curvula* (weeping lovegrass) and *Robinia fertilis* (bristly locust) are examples of species that are tolerant of extremely acid soils. Lower pH limits for selected species are listed in the chapters titled Revegetating Coal Surface-Mined Lands in the Eastern Coal Region and Revegetating Coal Surface-Mined Lands in the Western Coal Region.

Some species, such as *Sporobolus airoides* (alkali sacaton) and *Atriplex canescens* (fourwing saltbush), are more tolerant than other species of alkaline conditions. Many species grow well in soils with a pH lower than 7.9. A few species will tolerate moderately alkaline (pH 7.9 to 8.4) and strongly alkaline (pH 8.5 to 9.0) conditions; and even fewer species will survive very strongly alkaline (pH 9.1 and higher) conditions. In many areas with these alkaline conditions, there is the added problem of arid or semiarid climatic conditions.

Taking pH readings of the minesoils can provide an indication of where soil amendments are needed to neutralize acidity (lime) or to correct problems of alkalinity (gypsum). Field test kits are available to check pH but they should be calibrated against an approved laboratory pH meter. Generally, test kits with several indicator reagents are more accurate than kits with one reagent. Properly calibrated and maintained portable pH meters usually are more accurate than indicator test kits.

Investigations of the geologic strata by deep core drilling, collection, and analysis of samples for toxic levels of selected elements are needed. Preventive and corrective actions based on these investigations will minimize the

problems of very acid or very alkaline materials. Where possible, these materials can be buried well below the rooting zone of the common plants of the area.

Toxic Elements

Agricultural scientists recognize 16 elements as essential for the growth of green plants. The macronutrients are carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), potassium (K), sulfur (S), calcium (Ca), and magnesium (Mg). The micronutrients are iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), boron (B), and chlorine (Cl).

Several elements are considered toxic to plants, particularly when present in abnormally high concentrations. High concentrations of salts, too, may be injurious to plants. In soils, the elements most likely to be found in concentrations toxic to plants include selenium (Se), boron, aluminum (Al), manganese, iron, sulfur, arsenic (As), barium (Ba), nickel (Ni), copper, zinc, and lead (Pb). Where there are high concentrations of salts, such as in saline or alkaline soils, plants may be adversely affected by high concentrations of specific ions—sodium (Na^+), calcium (Ca^+), magnesium (Mg^{++}), potassium (K^+), chloride (Cl^-), sulfate ($SO_4^=$), bicarbonate (HCO_3^-), and boron (B^-). Several elements are toxic to plants only under very strongly acid (pH 4.5 to 5.0) or extremely acid (pH < 4.5) conditions. Aluminum, iron, manganese, copper, nickel, and zinc are elements that may be at toxic levels under strongly and extremely acid conditions.

In the western United States, many of the soils and the geologic strata are strongly alkaline (pH 8.5 to 9.0) or very strongly alkaline (pH 9.1 and higher). Under these conditions, molybdenum, boron, and selenium may be present in concentrations that are toxic to plants.

In the eastern United States, aluminum and manganese are the elements that occur most often in concentrations that are toxic to plants. Aluminum toxicity primarily reduces or inhibits growth of roots. Manganese toxicity reduces shoot or leaf growth. Raising soil pH to 5.5 or higher by applying lime will cause these toxic elements to precipitate from the soil solution and no longer be toxic to plants.

Nutrient Deficiencies

Nutrient deficiency often is a problem on reconstructed soils on surface-mined land. Nitrogen and phosphorus are most often deficient. Nitrogen levels are nearly always deficient for plant growth, especially where topsoil and associated organic matter are not replaced. Very acid and very alkaline soil or geologic materials are likely to have low levels of plant-available phosphorus. Applications of nitrogen and phosphorus fertilizers are nearly always beneficial in revegetating the reconstructed soils. Potassium fertilizer may not be needed for the initial establishment of vegetation, especially where unweathered overburden materials are part of the reconstructed minesoils. However, potassium levels may in time be reduced by natural weathering and leaching, and where vegetation is harvested and removed repeatedly.

No doubt, deficiencies of other macro and micronutrients exist on some minesoils, but in most situations these have not been defined. In some minesoils, imbalances of nutrients, such as between calcium and magnesuim, have caused problems with revegetation.

Physical Properties

A knowledge of several physical properties is important in evaluating soil as a medium for plant growth. These include bulk density, pore space, structure, texture (relative proportions of sand, silt, and clay particles), stoniness, slope length, slope steepness, slope aspect (direction), color of surface soil, erodibility of soil horizons, and stability. The presence of restrictive soil layers, such as fragipans, duripans, or calcic or petrocalcic horizons and depth to hard bedrock, are other important physical features.

As with potential chemical problems, the best solution to potential physical problems is to avoid them. Premining investigations of the soils and geologic strata can be helpful in planning how to separate and mix the various geologic strata during mining and grading so that materials left near the surface will have the best possible physical characteristics.

High bulk density probably is the most troublesome soil feature of reconstructed soils on surface-mined land. Moist bulk density is defined as the oven-dried weight of soil material (2 mm and less in diameter) per unit volume of soil, exclusive of rock fragments larger than 2 mm. It usually is expressed as grams per cubic centimeter. The symbol for bulk density is D_b or D_{bm}. Excessive compaction during soil handling operations may reduce pore space and produce bulk densities that restrict root extension (growth) and inhibit the movement of air and water within the soil. Bulk density is a good indicator of how well plant roots are able to extend into the soil.

As a general guideline, resistance to root extension is high where there is weak structure, no structure, or platy structure and the following combinations of soil texture and moist bulk density:

Texture	*Moist Bulk Density* (g/cm^3)
Sandy	1.85
Coarse-loamy	1.80
Fine-loamy	1.70
Fine silty, coarse silty	1.60
Fine	1.50
Very fine	1.35

Source: National Soils Handbook

The pattern of soil pores affects the movement of air and water within the soil and the resistance to root extension. Soil horizons with structure defined as strongly granular, blocky, prismatic, or columnar have much less resistance to root extension than similar soils where these structural qualities are weakly developed.

Soil texture (particle-size distribution) is determined by the relative amounts of sand, silt, and clay particles within a given soil horizon. Soil texture has a marked effect on many other physical features of soil such as water movement and retention, the amount of soil water available to plants, structure, bulk density, erodibility, consistence, and cation exchange capacity. Soil textures may be modified

by the presence of rock fragments. The descriptive names of these modifiers are related to size of the rock fragments. They include gravelly (2 to 7.6 cm diameter), cobbly (7.6 to 25 cm diameter), stony (25 to 60 cm diameter), and bouldery (> 60 cm diameter). The presence of rock fragments may influence handling of soil and land uses. Large rock fragments (stones and boulders) on or near the surface cause special handling problems during soil removal, storage, and reconstruction and may restrict land use capabilities.

Slope length, steepness, and aspect (direction) may affect species selection in some areas of the country and are an important consideration in soil reconstruction. Long and/or steep slopes have inherent erosion risks that must be addressed during soil handling and reconstruction. Erosion and sediment control structures may be needed on slopes to control erosion and assist in reestablishing the vegetation.

Soil color affects the temperature of the surface layers of a soil and is one of the considerations that needs to be addressed during soil reconstruction and revegetation of a given site. Dark colors absorb more heat from the sun's rays than light colors; thus, surface temperatures on dark soils can reach levels lethal to plant seedlings. High temperatures also hasten soil drying. On south to west exposures especially, the use of mulches may be necessary to help cool the soil surface and assist in establishing vegetation. In a given area, color may be a good clue to the chemical properties of selected geologic strata.

Soil erodibility is a measure of the susceptibility of a soil to particle detachment and transport by rainfall. Nomographs are available to estimate the erodibility factor (K) of different soil materials. Estimates of particle-size distribution, structure, and permeability are needed to use these nomographs. USDA Agriculture Handbook 537 (1978) provides background information on soil erodibility and the Universal Soil Loss Equation.

Biological Properties

Although not visually obvious, the biological components of soil often play a vital role in the development and maintenance of vegetation. In fact, the presence of microorganisms and soil fauna is essential for the long-term survival and growth of most plant species and for the reestablishment of natural ecosystems.

The biological component of soils consists of exceptionally diverse groups of organisms that range in size from easily seen plant structures, such as bulbs and rhizomes, and animals, such as insects and earthworms, to microscopic bacteria and fungi. These organisms, either individually or more characteristically in complex interactive roles, are an integral part of numerous physiological activities associated with plant and soil processes in natural soils. Many of these organisms have been identified with comparable activities on reconstructed soils of surface-mined lands. Such activities result in an increase in the availability of plant nutrients, particularly nitrogen and phosphorus; the decomposition or alteration of organic materials and subsequent accumulation of soil organic matter; and improvements in the structural properties of soils.

The establishment and rate of development of microorganisms in reconstructed soils are greatly influenced by the composition of the materials used in forming the planting medium and the availability of biodegradable organic matter. The planting medium may consist of a topsoil, an approved substitute material, or mixtures of the two. One potential benefit of using topsoil is to reintroduce and increase the availability of beneficial microorganisms. Where reforestation, wildlife habitat, and range are planned postmining land uses, the presence of seed, rhizomes, bulbs, or other plant reproductive structures in the replaced topsoil may aid or hasten the reestablishment of native vegetation.

Where topsoils are used, surface horizons often are removed separately and segregated. In many instances, the topsoils are stockpiled for some period of time before they are redistributed over the graded overburden materials. With increased time of storage there is a decrease in both oxygen and moisture, a substantial loss in organic matter and soil structure, and a marked reduction in the microbial population. Shallow, wide piles are preferable if topsoil must be stored; however, the best practice is the direct haul method, which eliminates stockpiling, saves costly rehandling, and helps maintain an active microbial population. In some regions, the chemical properties of substitute materials make them equal or better plant-growth media than highly leached and severely eroded surface materials. Where substitute materials are used in these situations, the organic materials provided by mulching and a lush growth of herbaceous vegetation may be more beneficial than the poor-quality surface soil materials in establishing and stimulating microbial activity.

Transformation of Nitrogen

In most instances, agricultural fertilizers with various formulations of ammonia and nitrate are used to establish herbaceous vegetation required for early stabilization of reconstructed soils. While such fertilizers represent the initial increase in soil nitrogen levels in these soils, subsequent increases and maintenance levels of nitrogen are primarily due to ammonia produced during biological fixation of atmospheric nitrogen and to various forms of nitrogen released following microbial degradation of organic materials. Biological fixation of nitrogen is predominantly a function of bacteria living in root nodules of compatible host plants. One of the more common of these groups of bacteria, *Rhizobium*, forms a symbiotic association (an association between two organisms that is beneficial to both) with both herbaceous and woody legumes, such as *Trifolium* spp. (clovers), *Lespedeza* spp., and *Robinia pseudoacacia* (black locust). Another group, *Frankia*, is associated with nodules of nonleguminous shrub and tree species, such as *Elaeagnus umbellata* (autumn olive), *Alnus* spp. (alder), *Ceanothus* spp., and *Purshia* spp. (bitterbrush).

Biological nitrogen-fixation also occurs to a limited extent by asymbiotic or free-living (non-nodulating) bacteria, such as *Azotobacter* and *Azospirillum*, frequently encountered in soils surrounding the root system of grasses, and by *Clostridium* in anaerobic soil conditions in which oxygen is limiting or absent. Asymbiotic bacteria are only occasionally reported in highly fertilized agricul-

tural soils and are thought to contribute little to the total nitrogen economy of such soils. However, where present in reconstructed soils, they may be much more significant, particularly where nitrogen is a limiting factor.

One of the major reasons for using symbiotic nitrogen-fixing plants is to increase the soils levels of nitrogen sufficient to maintain growth of non-nitrogen-fixing revegetation species. Since nitrogen fixed in these plants is released following microbial degradation, there may be a considerable time lag before plant residues are decomposed and the fixed nitrogen is released and made available to the nitrogen pool. By contrast, the asymbiotic bacteria have a relatively short life span, and the nitrogen incorporated by these organisms is available to the nitrogen pool within days or weeks after fixation.

As shown in the abbreviated diagram of the nitrogen cycle, ammonia is readily assimilated by both plants and microorganisms and is used to produce amino acids, the building blocks of the protein fraction of organic materials (Figure 1). Such materials decompose gradually and the reverse reaction occurs, whereby amino acids of proteins are broken down and ammonia is again released. The ammonia may be recycled through newly formed organic materials, or may be strongly attached to surfaces of clay minerals or humic materials, thus representing a reservoir of nitrogen which may be used later for plant and microbial growth.

The diagram of nitrogen cycle shows that under aerobic soil conditions, ammonia also may be converted to nitrate by nitrifying bacteria (Figure 1). This nitrate, as well as the nitrate component of agricultural fertilizers, may be assimilated by plants and soil microorganisms. Nitrate is highly water soluble and is leached rapidly from the upper soil layers during periods of excessive rainfall or snowmelt. With such high infiltration rates, the normal air spaces in these soils become filled with water, resulting in an anaerobic condition. As indicated in the anaerobic portion of the nitrogen cycle, bacteria such as *Clostridium* may recover some of the nitrates through nitrogen fixation; however, the major portion of nitrates are lost in the subsequent denitrification process. Other groups of bacteria transform nitrates to nitrites, which quickly undergo biological conversion into two gaseous states of nitrogen, nitrous oxide and nitrogen. These gases escape from the soil to the air, resulting in a reduction of the nitrogen content of the soil.

Mycorrhizal fungi are essential microorganisms in the revegetation of reconstructed soils. Such fungi increase the solubility of minerals, improve uptake of nutrients for host plants, produce plant growth hormones, bind soil particles into stable aggregates, and translocate organic carbon and nitrogen compounds from one plant to another. Endomycorrhizae and ectomycorrhizae are specialized plant roots formed as a result of a mutualistic symbiosis between beneficial soil fungi and fibrous roots of the host. Carbohydrate requirements for growth of the fungus are provided by the host plant, while the fungus, in turn, supplies organic nutrients essential for plant growth and development. Mycorrhizal fungi grow between or into cells of these roots and produce external strands of hyphal growth (mycelium) from the mycorrhizae into the surrounding soil. Mycorrhizal plants with abundant external hyphae have greatly increased surface areas for absorbing water and mineral nutrients important in plant nutrition.

Nitrogen and carbon compounds produced during microbial degradation of plant and other organic residues are taken up and translocated by the external hyphae into the rooting zone or are stored in the fungal tissue. These compounds also may be translocated from one plant to another by a shared mycorrhizal mycelium. The mobilization and fungal retention of nitrogen in the rooting zone are advantageous for reconstructed soils particularly where plant development is advanced and where ammonium-nitrogen is the primary source of plant-available nitrogen.

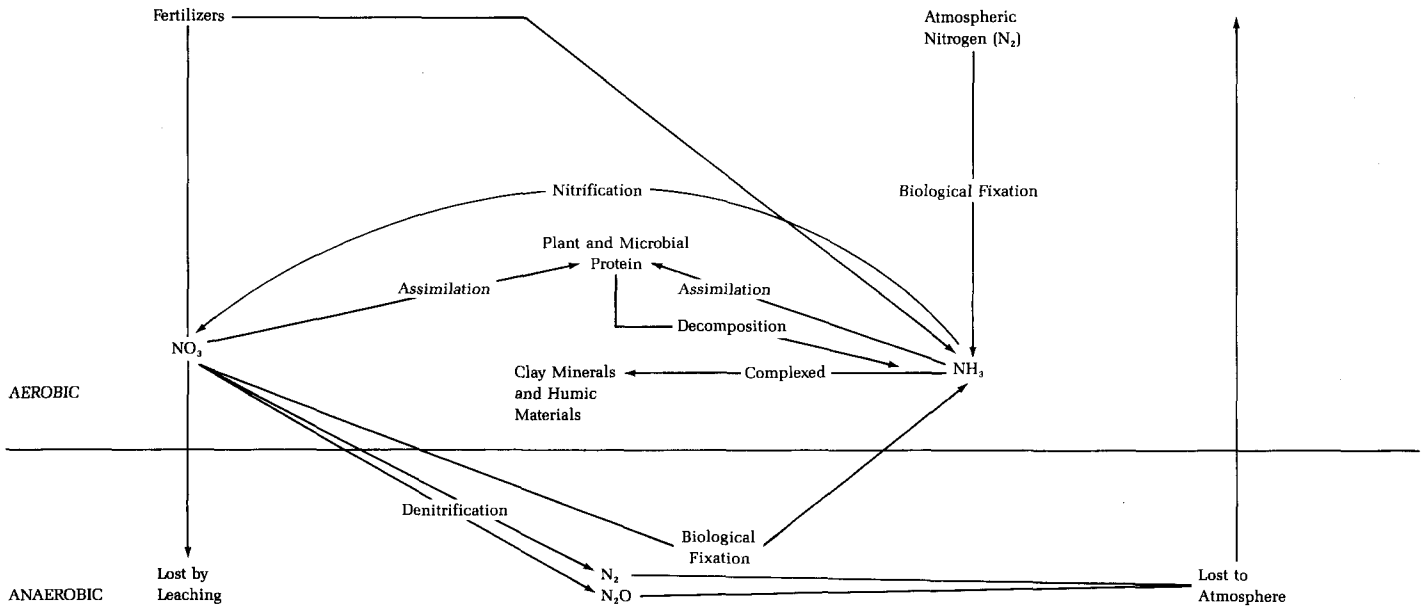

Figure 1. The nitrogen cycle.

Decomposition of Organic Materials

Various types of mulching materials are frequently used on reconstructed soils to help control erosion until plant growth is established. In conjunction with their known physical benefits, many woody residues—freshly prepared whole tree chips, shredded bark, hay, straw—are the source of water-soluble organic materials that percolate into the planting media and are readily utilized by soil microorganisms. The bulk of the material that remains consists of insoluble materials such as cellulose and lignin. These residues and the plant litter that accumulates on the soil surface following plant establishment are resistant to attack by the majority of microorganisms. However, when present, soil animals are particularly important in the decomposition process of these materials. Certain insects and earthworms are primarily responsible for consuming plant litter and burying or mixing it in the soil. Ingestion of woody materials by these animals increases the surface area and water absorption properties of the materials and alters or modifies the chemical properties for more ready decomposition by soil microorganisms.

Of the organic mulches commonly used, wood chips and bark are among the most resistant to microbial degradation and are only slowly degraded by certain of the higher fungi. Under natural conditions, many of these fungi produce and excrete substantial quantities of organic acids as part of their normal metabolic activity. One of these (oxalic acid) reacts with calcium released during degradation of wood to form calcium oxalate, which is important in both the soil chemistry and plant nutrient cycles in reconstructed soils. Calcium is required in considerable quantities during root growth and development and may be temporarily reduced in the soil solution by vigorous plant growth. Under these conditions, the calcium oxalate crystals produced during the degradation of mulches may serve as a reservoir of calcium in that the small, relatively insoluble crystals are carried by water into the plant root zone where they are either decomposed by microorganisms or go into soil solution. With either action the calcium portion of calcium oxalate that is released is used to sustain plant growth.

Phosphorus is another element essential for plant growth in reconstructed soils. Where present in concentration sufficient to influence the chemistry of these spoils, iron and aluminum may form hydroxides that react with and effectively remove phosphates from the soil solution. However, during the decomposition or dissolution of calcium oxalate in the soil, as noted previously, the oxalate portion that is released combines with iron and aluminum and inhibits their reaction with and removal of plant available phosphorus from the soil solution.

Soil Aggregation

The establishment of vegetation improves the structural properties of most soils, particularly the formation and stabilization of soil aggregates. Aggregate stability is one of the most significant soil properties influencing surface erosion, and on minesoils it is known to vary with the vegetation types. In most instances, annual and perennial grasses are used to achieve a quick ground cover to help reduce water runoff and soil erosion. The extensive fibrous root system of the grasses not only presents a physical barrier to soil erosion but also releases organic materials (carbohydrates) that function either directly in aggregating soil particles (i.e., rhizosheath) or indirectly as carbon and energy sources during microbial production of soil-binding agents. During active vegetative growth, both annual and perennial plants appear to be equally effective in providing nutrients for microbial activities leading to aggregate formation, though aggregate stability is more characteristically observed under perennial plants. Physiological properties that differ in some grasses may quantitatively or qualitatively influence the development of soil structure. Some of the revegetation species have a rapid rate of photosynthesis (production of carbohydrates) and a high growth rate, and thus secrete more of the carbohydrates to the surrounding soil. Since many of the bacteria and mycorrhizal fungi derive much of their energy directly from plant roots, the host plants noted may have a greater influence than other hosts on the production of soil binding agents by these microorganisms.

Soil Profile Descriptions

Descriptions of the soil profiles at representative sites are an essential part of the baseline information needed from a permit area. These descriptions need to be prepared according to the standards of the National Cooperative Soil Survey and should be prepared before mining. Soil profile descriptions also are needed after soil reconstruction has been completed.

In preparing soil descriptions, soil scientists describe each distinguishable horizon or layer. The different kinds of layers are identified by symbols (A, E, B, and C). These designations are assigned after comparing the observed characteristics of the layer, such as color, texture, structure, consistence, and pore space, with properties inferred for the material before soil formation.

In describing each soil horizon, the soil scientist observes and records the following features where present:

- Depth and thickness of the horizon.
- Boundary of horizon.
- Soil texture and rock fragments.
- Soil color (Munsell color chart notations—hue, value, and chroma).
- Size, shape, contrast, and color of mottles.
- Moisture status.
- Structure, including shape, size, and grade.
- Surface features, such as clay skins, slickensides, and sand or silt coats.
- Nodules and concretions.
- Consistence, including strength, plasticity, stickiness, and fluidity.
- Pores
- Roots and root traces.
- Animals and their traces.
- Soil reaction (pH).
- Carbonates.
- Salinity.
- Sodicity.
- Gypsum.
- Sodium sulphate.
- Sulfides.
- Other features.

Horizons

Soils are composed of horizons (layers) of soil material that are parallel or nearly parallel to the land surface (Figure 2). The four master soil horizons recognized in the surface-mining regulations are A, E, B, and C. Two other master horizons are recognized by the National Cooperative Soil Survey. These horizons are the O and R.

- A horizon—the uppermost mineral layer, often called the surface soil. It is the part of the mineral soil in which organic matter is most abundant, and where leaching (eluviation) of soluble and suspended particles is typically the greatest. The A horizon together with the E horizon is defined as topsoil by the surface-mining regulations.
- E horizon—the transitional layer between the overlying A horizon and underlying B horizon. An E horizon is most commonly differentiated from an overlying A horizon by lighter color and generally has measurably less organic matter than the A horizon. An E horizon is most commonly differentiated from an underlying B horizon in the same sequence by color of higher value and lower chroma, by coarser texture, or by a combination of these properties. The main feature of the E horizon is the loss of silicate clay, iron, aluminum, or some combination of these, leaving a concentration of sand and silt particles of quartz or other resistant minerals.
- B horizon—the layer that typically is immediately below the A horizon, or E horizon where present, and often called the subsoil. This middle layer commonly contains more clay, iron, or aluminum than A, E, or C horizons. This layer is dominated by the destruction of all or most of the original rock structure and by 1) accumulation (illuviation) of silicate clay, iron, aluminum, humus, carbonates, gypsum, or silica alone or in combination; 2) evidence of removal of carbonates; 3) residual concentration of sesquioxides; 4) coatings of sesquioxides that make the horizon lower in value, higher in chroma, or more reddish in hue than overlying and underlying horizons though without apparent illuviation of iron; 5) alteration that forms silicate clay or liberates oxides or both, and that forms granular, blocky, or prismatic structure when volume changes accompany changes in moisture content; or 6) varying combinations of these.
- C horizon—the layer beneath the B horizon. It consists of loose material or weathered bedrock that is relatively unaffected by biological activity and other soil-forming processes. This layer lacks properties of the O, A, E, or B horizons. The material of the C horizon may or may not be similar to that from which the solum (horizons above the C) was presumably formed. Included as C layers are loess, glacial till, sediments, saprolite, and consolidated bedrock that when moist can be dug with a spade.
- O horizon—the layer generally dominated by organic material. O horizons occur on top of mineral or organic soils or may be buried beneath mineral soil horizons. Some soils consist entirely of material designated as O horizons.
- R horizon—an underlying layer of hard (consolidated) bedrock. Granite, basalt, quartzite, and indurated (hardened) limestone or sandstone are examples of bedrock designated R.

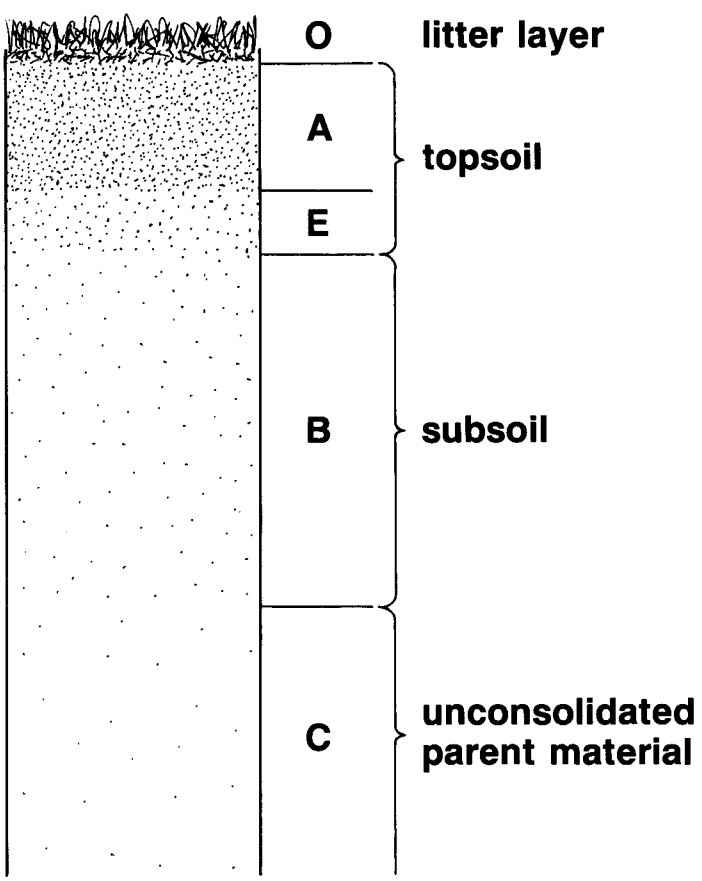

Figure 2. Soil horizons in a mineral soil profile.

Recognition of Undesirable Strata

Undesirable strata may be a potential problem in soil removal, storage, and reconstruction. Some genetic soil horizons have properties that impede or prevent the extension of plant roots and, in some cases, infiltration of water. Among these are fragipans, duripans, calcic horizons, salic horizons, gypsic horizons, natric horizons, petrocalcic horizons, and petrogypsic horizons. Some argillic horizons that are high in clay content and low in pore space also may impede root growth. Some argillic horizons may have toxic levels of aluminum.

The mine inspector may need to consult with soil scientists from the U.S. Department of Agriculture or from agricultural universities for assistance in identifying some of these genetic horizons or for help in interpreting soil descriptions and soil characterization data.

Where plant growth appears to be vigorous on unmined sites within the permit area or on nearby sites with similar soils, there is little likelihood of having materials that severely impede root growth within the normal rooting depths of the common trees and crops of the area. A review of available soil characterization data may be helpful in giving warning of possible problems of toxicity.

When the inspector is uncertain about the presence of undesirable chemical or physical characteristics in the soil, he or she should consult a soil scientist and have soil samples collected and sent to an approved laboratory for analysis.

Undesirable geologic strata may occur below the solum (A, E, and B horizons) in the permit area. Soft or hard bedrock may occur at relatively shallow depths and there may be outcrops of this bedrock in some places on the landscape.

Geologic Strata

The characteristics of the geologic strata below the soil and above the coal seams are important in that they determine the possible use of selected strata as substitute root-growth media. These characteristics also determine the need to bury selected strata below the root zone of the common trees and crops to avoid toxicity.

Substitute Materials

The use of geologic materials as substitutes for the A, E, B, or C horizons in the soil reconstruction process should be considered only where there are severe restrictions to root growth imposed by the genetic horizons, and it can be demonstrated that the substitute material will create a root zone with equal or more favorable characteristics. In most cases, the soil horizons have better physical and chemical characteristics than the geologic strata beneath the soil.

In areas where the soils are thin or where there are genetic soil horizons that impede plant growth, it may be desirable to use selected geologic strata from the overburden in place of the B or C horizons in the soil reconstruction process. Examples of genetic horizons that impede plant growth include fragipans, duripans, calcic horizons, petrocalcic horizons, natric horizons, gypsic horizons, petrogypsic horizons, salic horizons, and sulfuric horizons. It is most ill advised to attempt replacement of these genetic horizons during soil reconstruction even where they are part of an otherwise desirable soil profile. In fact, the overall physical quality of the reconstructed solum might even be improved by carefully preventing the replacement of these materials.

Where substitute materials are being considered or proposed, a careful review of existing characterization data should be made. This would include review of soils data as well as data from laboratory tests of samples of geologic strata collected during the core drilling of selected sites on the permit area. It may be necessary to obtain additional laboratory tests of selected geologic strata to check for the presence of toxic materials before a decision is made on the use of substitute materials.

Toxic Substances

It is not uncommon to find geologic strata in the overburden that contain concentrations of sulfur, iron, manganese, aluminum, boron, selenium, or other elements that will be toxic to plant growth if these strata are placed within reach of plant roots during soil reconstruction (Figure 3). Oxidation of iron sulfides in the coal or geologic strata above the coal seams is the primary cause of extremely acid conditions and toxic levels of selected elements when these strata are placed on or near the surface during the reconstruction process. Where laboratory data show the presence of iron sulfides or concentrations of other elements that may be toxic to plant growth, care should be exercised during removal and replacement to bury the strata containing these substances well below the rooting depth of the common trees and crops of the area. In some regions, however, burial of such materials may create subsequent problems with subsurface acid-mine drainage. Thus, other procedures for handling and treating acid or toxic strata may be required.

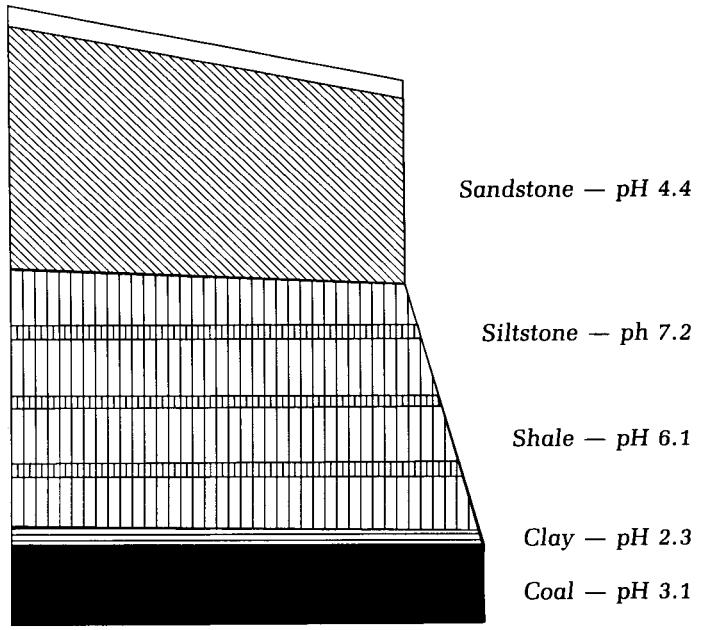

Figure 3. Highwall section of Hazard No. 9 coal seam in eastern Kentucky.

Sampling and Testing Minesoils

A knowledge of soil properties usually is obtained by analyzing or testing samples from areas that are ready for planting. Soil tests are useful mainly for defining properties that limit or prevent plant growth and for determining the kinds and amounts of amendments needed to correct properties that hinder the establishment of vegetation. This section discusses sampling procedures and soil tests used for analyzing reconstructed soils and minesoils, including reasons why the tests are useful and some of their limitations.

Soil Sampling

Samples should be representative of the area that is to be vegetated. Normally, samples should be collected after shaping, grading, and soil replacement have been completed. Before sampling, one should inspect the entire site. Areas that obviously are different from others in color and rock or soil type should be sampled as individual units, especially if they are large enough to be handled separately in the revegetation program. But even small areas that appear toxic or vastly different should be sam-

pled separately because they may require special treatment for establishing vegetation. Delineating the different types of minesoil on a map of the mined area could help facilitate the reclamation activities.

A recommended method of sampling is to make a composite sample from several randomly collected subsamples in each visually distinct unit or type of soil. The number of subsamples needed for the composite sample will depend on the size of the unit, the variability of materials within the unit, and the objective of revegetation. At least 10 subsamples are needed for each composite sample in areas up to about 10 acres. More subsamples are recommended in larger areas, or more than one composite sample could be collected. Areas planned for agricultural uses probably will require more intensive sampling than areas planned for reforestation. An advantage of the composite sample is that soil from the entire unit is represented in the sample, but only one sample for each unit needs to be sent to the laboratory for analysis. Remember, the composite sample is realistic only if it represents the soil in the area from which it is collected. Each composite sample should be representative of only one soil type. If even 1 of 10 subsamples is from an acid spot, the composite sample may be dominated by this single acid subsample.

To describe and map an area in greater detail, all samples can be kept separate and analyzed individually, and the sample locations shown on the reclamation map. A disadvantage of individual sampling is the greater cost for collecting and labeling samples and for laboratory analyses.

The number of samples collected also may depend on the number and kinds of soil tests that will be made. For example, if only pH is to be determined, many samples could be analyzed at relatively low cost. But tests for nutrient availability, potential acidity, and other items will increase costs. Some States may provide guidelines or specify the kind of analyses and the number of samples that should be collected.

To collect soil samples, use a tile spade with a rounded cutting edge or a small garden spade. First, make a vertical cut about 4 to 6 inches deep and discard the soil. Then make a second cut 2 to 3 inches behind the first cut to obtain the sample. Discard rock fragments larger than about ½-inch in diameter. If a composite sample is being collected, place this slice of soil in a plastic bucket and continue on to the next sampling site and repeat the sampling procedure. In stone-free soils, samples can be collected with an agricultural soil-sampling tube or auger. After the final subsample has been placed in the bucket, thoroughly mix the composite of samples and transfer about 1 quart of the mixed material to a plastic bag, wax- or plastic-lined paper carton, or similar container. Dry samples can be placed in paper bags. Be sure to identify and label each sample. If the minesoil at each sample point is to be analyzed, follow the previously mentioned procedure for obtaining the sample, but place each sample in a separate fully labeled container.

After all samples have been collected, they should be air dried or dried with artificial heat at low temperatures (40° to 60°C), either in a paper bag or spread out on paper in a dust-free area. When dry, place a portion of each sample in a container recommended or supplied by your testing agency. The State soil test laboratory in some States may provide testing services specifically for minesoils either directly or through county extension agents. In other States, minesoil tests may have to be obtained from commercial laboratories.

In routine or standard agricultural procedures, as just described, samples are collected to a depth of about 6 inches. However, at many sites, reconstructed soils offer a potential rooting depth exceeding that on the undisturbed native soils. Such soils, then, seem especially well suited for growing deep-rooted plants such as trees, shrubs, and some leguminous herbs. Where such plants are to be established, consideration should be given to sampling the soils to a greater depth, possibly as much as 4 to 5 feet, in the anticipated rooting zone of the plants. This is especially valid in view of mining and reclamation practices, such as burial of undesirable overburden materials and replacement of soil on the surface, that will cause variation in the chemical and physical properties of the minesoil at varying depths below the surface.

Sampling spoils to a depth of several feet also is important in planning the rehabilitation of abandoned mined lands, especially where movement and grading of spoils are anticipated: in the process of grading off several feet of spoil, different materials may be uncovered and exposed that have chemical and physical properties that are even more undesirable than those presently on the surface.

Obtaining samples from a depth of several feet will require additional effort and probably additional equipment. Where stones and rock fragments do not interfere, a soil-sampling tube or a post-hole digger or auger could be used. In more stony material, a pit may have to be dug with a spade and shovel or back hoe. Samples should be collected at prescribed depths, say at every foot, or from each layer of material that appears visibly different from other layers. Obviously, if material with adverse properties is found in most of the test profiles, a change in plant types or species may be required.

Soil Tests

Because topsoil or subsoil, or both, are spread over most surface-mined lands before reclamation, the soil tests recommended by the local extension service and/or State Agricultural Experiment Stations usually are the best guides to fertilizers and amendments needed for attaining vegetative cover. Soils and their associated problems differ markedly from mine to mine, state to state, and region to region. Soil tests that work well in one area may not be appropriate in another.

At some mine sites, other overburden materials (spoil) may be available that make a better plant-growth medium than the local topsoil. This situation may occur where the local topsoil is extremely shallow, stony, sandy, brick-like, sodic (high in exchangeable sodium), saline (high in soluble salts), or perhaps exceptionally infertile. Tests that provide guidance in regard to the nutrient and amendment needs of the local topsoils may not do so when used on mine spoils, because the minerals (and sometimes salts) commonly found in unweathered spoil materials may interfere with tests used to evaluate agricultural soils. The

main interest here is with those tests that generally are applicable to all minesoil materials and that point out problems that must be addressed before good vegetative growth can be obtained. Where more than one type of spoil seems suitable for use as a topsoil substitute, the following recommended soil tests should show which material is likely to be the best.

Many kinds of soil tests can be made, but for most revegetation jobs, tests for only a few chemical characteristics are needed to determine the plantability of the minesoil and prescribe the required amendments (Table 1).

Particle-size Analysis

In this analysis, a soil is classified by the relative weights of its various particle-size groups. Particles greater than 2 mm in diameter are classed as gravel, rocks, boulders, etc., and in weathered soils generally are considered to be inert (i.e., neither affecting the soil chemistry nor contributing to plant nutrition). In spoils, some of the unweathered coarse fragments may weather rapidly and release plant nutrients. The fine-earth fraction of soils includes silt, clay, and sand particles less than 2 mm in diameter. The proportions of these separates in soil determines its textural class.

Generally, the finer the particles the greater their value in holding nutrients and moisture available for plant use. Sand particles are the largest of the soil separates. They contribute little to the chemical activity of soil but increase the amount of space between particles, which facilitates movement of air and drainage of water. A high content of sand in soil causes low water-holding capacity and drouthiness. Silt contributes to some chemical activity and may yield appreciable amounts of nutrients. Soils high in silt are capable of holding the most available water for plant growth. The clay separate is composed of the smallest particles and is the most active chemically. Soils high in clay have the greatest total water-holding capacity but are less efficient than silty soils in giving up water for plant growth.

Physical appearance alone may be adequate to classify some minesoils as unsuitable growth media. A soil composed almost totally of rocks, boulders, cobbles, pebbles, and/or coarse sand will not support a good growth of plants. Deep-rooted plants are more likely to succeed than shallow-rooted plants in coarse-textured soils containing little silt or clay.

Tests using Saturation Paste and 1:1 Soil:Water Extracts

Distilled or deionized water must be added to a soil before its pH can be determined. This same water must be extracted before its specific conductance can be measured or the individual dissolved constituents analyzed. For analytical tests to be relevant to field conditions, it is essential that no more water be added than is necessary for the tests. A saturation paste can be prepared easily in the field and is readily reproducible. It is prepared by adding water to the soil sample until the surface of the stirred mixture glistens with excess moisture. This paste should be stirred occasionally for an hour or two to facilitate chemical equilibrium between the soil and the added water before measurements are made. It may be necessary to add more water if the paste ceases to glisten. When a satura-

Table 1. Recommended postmining soil/overburden tests.

Chemical Characteristics	*Soil*	*Overburden*
Fertility		
pH	Yes	Yes
Nitrogen		
Organic matter	Yes	Yes*
Total N	S†	S*
Water Soluble NH_4 and NO_3-N	Yes	Yes
Mineralizable N	S	S
Phosphorus (Plant available)	Yes	Yes
Bray No. 1		
$NaHCO_3$ on calcareous soils (pH > 8.0)		
Potassium (Plant available)	Yes	Yes
Iron, zinc, manganese, selenium, boron, copper, (water or double acid extractable)	S	S
Calcium, magnesium, sodium (water extractable)	S	S
Lime		
Acid test (qualitative)	Yes	Yes
Quantitative	S	S
Cation exchange capacity	S	S
Salinity-sodicity		
pH	Yes	Yes
Soluble salts (EC on saturated paste)	Yes	Yes
Water soluble Ca, Mg, Na, K	Yes	Yes
Sodium adsorption ratio	Yes	Yes
Exchangeable sodium percentage	S	S
Water-soluble anions (CO_3, HCO_3, SO_4, Cl, NO_3)	S	S
Gypsum	S	S
Acidity		
pH	Yes	Yes
Lime requirement		
Buffer pH	Yes	S
Total potential acidity (by total sulfur determination procedure)	No	Yes
Neutralization potential (Natural liming ability)	No	S
Acid-base accounting (used with potential acidity)	No	S

*Interpretations difficult.
†S = In special situations.

tion paste is coarse grained or sandy, it may be possible to extract sufficient water for further tests by gravity flow through filter paper. When a saturation paste contains appreciable silt or clay, it will not be possible to extract the soil solution without using either vacuum or pressure to draw or force the water from the soil and through the filter. Vacuum can be obtained in the field by tapping into the manifold of an automobile or truck engine.

Extracts from a 1:1 soil:water mixture usually are easier to obtain (simple filtration through a filter paper) and use in field tests, but generally are not as representative of field conditions as the saturation paste. A 1:1 soil:water extract adequate for field tests can be prepared by adding distilled or deionized water equal to the weight of the air-dry soil, then stirring or shaking the sample periodically for about 2 hours. For the analysis, use the solution that will drain from the mixture through a fine- or medium-pore filter paper. The use of vacuum or pressure will speed the filtration process and may be necessary when the 1:1 mix is high in clay. In rare instances, the soil may contain so much bentonite or similar type clay that water cannot be extracted from a 1:1 soil:water mixture. In these cases, a soil:water ratio of 1:2, 1:5, or even 1:10 may be required.

It is not necessary to have a perfectly clear sample for measuring specific conductance, but a clear, sediment-free extract is required for determining individual chemical constituents. Procedures given here are adequate for field tests but more sophisticated techniques would likely be used in a soils laboratory.

Specific conductance

Specific conductance gives an approximation of the total dissolved salts in the extract, and, by inference, in the original soil solution as it existed under field conditions. Excessive salt concentrations in soil solutions will suppress plant growth but some plant species are much more sensitive to salts than others (Table 2).

Table 2. Crop sensitivity to salts (electrical conductivity) determined by saturation extract test.*

Crop	Expected Yield Reduction 0%	10%	25%	50%
	mmhos/cm			
Tall wheatgrass	7.5	9.9	13.3	19.4
Wheatgrass	7.5	9.0	11.0	15.0
Bermudagrass	6.9	8.5	10.8	14.7
Barley	6.0	7.4	9.5	13.0
Perennial ryegrass	5.6	6.9	8.9	12.2
Trefoil: birdsfoot, narrowleaf	5.0	6.0	7.5	10.0
Tall fescue	3.9	5.8	8.6	13.3
Vetch	3.0	3.9	5.3	7.6
Big trefoil	2.3	2.8	3.6	4.9
Alfalfa	2.0	3.4	5.4	8.8
Weeping lovegrass	2.0	3.2	5.2	8.0
Corn (forage)	1.8	3.2	5.2	8.6
Orchardgrass	1.5	3.1	5.5	9.6
Clover: alsike, ladino, red, strawberry	1.5	2.3	3.6	5.7

*From Evangelou and Grove, 1982.

Special Tests for Saline Soils

Specific conductance in excess of 2 millimhos/cm (2,000 micromhos/cm) indicates other potential problems and the need to submit samples to a laboratory for further analysis. A 1:1 or saturation paste extract of these samples should be analyzed for boron, nitrate, the common dissolved ions (calcium, magnesium, sodium, potassium, sulfate, and chloride), and alkalinity or acidity. In addition, a 1:10 soil:water mixture should be shaken overnight and the extract analyzed for sulfate, calcium, and magnesium; the first ion indicates whether or not gypsum will cause a problem, and the last two ions show the potential for an imbalance of calcium to magnesium.

Boron in excess of 1 mg/l in the saturation paste or 1:1 extract may be toxic to many plants. Magnesium in excess of 500 mg/l in the saturation extract may make it difficult to establish a good vegetative cover. The ratio of calcium to magnesium (Ca and Mg measured in units of mg/l) should be within the range of 0.35 to 11 (tentative limits subject to revision); if not in this range it may indicate a calcium/magnesium imbalance that is toxic to most plants. When these calcium:magnesium ratios are less than 1, the soils or spoils may mimic the physical characteristics of soils with a high sodium-adsorption-ratio (SAR).

The SAR is calculated from calcium, magnesium, and sodium concentrations found in the 1:1 or saturation paste extracts by the formula: $NA^{+}/(Ca^{++} + Mg^{++})$ where Na^{+}, Ca^{++}, and Mg^{++} refer to the concentrations of designated cations expressed in milliequivalents per liter. (See USDA Agricultural Handbook 60, p.5, 26, 103, 1954.) An SAR ratio in excess of 13 percent indicates that the exchangeable-sodium-percentage probably exceeds 15 and that the soil or spoil will likely have poor physical characteristics—brick-like and almost impenetrable by water or air when dry. Such soils have a pH in excess of 8.3 and a black appearance due to the deposition of previously dissolved organic matter on the soil surface—a condition commonly referred to as "black alkali,"

pH

Tests for pH are most frequently used for assessing acidity or alkalinity and predicting plantability of soils and spoils. A pH meter is the standard device for measuring pH because it is the most accurate. A common practice is to collect samples of soil and send them to a laboratory equipped with a pH meter. Battery-operated pH meters can be obtained for field use. Some disadvantages of using pH meters in the field are that delicate handling and maintenance are required, and that containers, distilled water, and buffer solutions must be transported.

Several types of field kits and other devices are available for measuring soil pH. However, some of these do not give accurate readings on all soils, and especially spoils, when compared with the pH meter. Field kits such as the LaMotte-Morgan that use several pH indicator dyes agree more closely with the pH meter than some field kits that use only one indicator dye. Before any commercial field kit or other device is adopted for widespread use, it should be compared with a pH meter to determine if it can provide reliable readings.

Distilled water or distilled water containing a neutral

salt solution such as 0.01M $CaCl_2$ must be added to soil before pH measurements can be made with a pH meter. Enough water should be added to form a saturated paste (the surface glistens with free water) or to form a 1:1 dry soil:water ratio. More water than this in the soil may result in pH values that are not representative of field conditions. Field pH meters are sometimes inaccurate even though they have been calibrated properly against buffers, generally because of sluggishness or otherwise defective electrodes. Field pH meters should be checked periodically against more accurate laboratory pH meters using actual soil samples. The procedures used for measuring soil pH may differ among States and from lab to lab, and data from the different methods may not be directly comparable. One popular and, in some ways, advantageous procedure calls for determining the pH on soil wetted with .01M $CaCl_2$ water.

Lime Requirements

The pH readings indicate where problems with soil acidity or alkalinity may be encountered. But pH does not indicate the quantity of amendment needed to correct problems of acidity or alkalinity. Methods for determining lime requirements in agricultural soils differ among States; but some methods do not adequately predict lime requirements for acid coal-mine spoils. Therefore, methods should be used that have been determined by qualified soil test facilities to be reasonably accurate for testing minesoil materials in a given area.

SMP Buffer pH—The Shoemaker, McLean, and Pratt (SMP) Buffer pH method is used in several eastern States and is reasonably accurate for determining lime requirements for both agricultural soils and most minesoils. It is a fast, routine test developed for acid soils that contain appreciable amounts of exchangeable aluminum, but may underestimate lime requirements for rock or spoil materials containing unoxidized sulfur compounds. Rates of limestone required to raise soil pH to 5.5 and 6.4 as determined by the SMP Buffer pH test are shown in Table 3.

Lime Requirement for Highly Acidic Minesoils—When buffer pH readings are below 4.0, the minesoils usually are difficult to revegetate and may require special treatment during reclamation. A total sulfur analysis on these highly acidic materials can be used to indicate the maximum amount of lime needed to neutralize active and potential acidity: 31.3 tons of lime for each percent of sulfur present. Lower levels of lime may be adequate if any of the sulfur is in more reactive forms. An alternate plan may be desirable, such as adding at least 25 tons of lime per acre, incorporating it, and retesting the minesoils in 4 to 6 months. A cover crop, which also may serve as a mulch to further aid in establishing permanent vegetation, should be seeded during this period to reduce erosion. Be sure that any needed lime and fertilizer, based on the new test, are added before seeding further. If this alternate plan is not used and sulfur tests are not available, apply about 1.5 times the maximum rate of lime given in Table 3.

Exchangeable Acidity and Exchangeable Aluminum—Lime requirements for acid minesoils also can be based on tests that directly determine exchangeable acidity or exchangeable aluminum. Much evidence is available to show that the beneficial effects of liming are largely due to the inactivation of exchangeable aluminum. The amount of lime necessary to negate the effects of exchangeable aluminum usually is sufficient for productive plant growth, but it may be less than that required to raise pH to the theoretically optimum 6.5 often recommended for agricultural purposes.

Table 3. Limestone rates for spoil-buffer pH readings.

Buffer pH Readings	*Agricultural Limestone Rates at pH* 5.5	6.4
	tons/acre	
6.7-6.3	1-2	2-4
6.3-5.9	2-4	4-6
5.9-5.3	4-6	6-8
5.3-5.0	6-8	8-11
5.0-4.5	8-11	11-15
4.5-4.0	11-15	15-25
Below 4.0	(see discussion on Lime Requirement for Highly Acidic Minesoils)	

Laboratory procedures for determining exchangeable acidity and aluminum may vary; thus, criteria for lime requirements need to be established for each extraction procedure and for different geologic types. For example, with the aluminum extraction procedure described by Yuan (1959), a satisfactory criterion for liming many of the minesoils in eastern Kentucky is to apply 2,000 pounds per acre of $CaCO_3$ equivalent for each milliequivalent of exchangeable aluminum (meq/100 g).

Potential Acidity—The preceding tests measure active or exchangeable acidity in minesoils, but not the total potential acidity that may be produced from further oxidation of pyritic material. Potential acidity will most likely cause revegetation problems in freshly exposed, unweathered geologic materials, or in extremely acid spoils that are partially weathered but still contain oxidizable pyrite. With freshly exposed materials, standard lime requirement tests, including the SMP Buffer pH test, may initially show little need for lime; but as the rock materials weather, acidity will increase and much more lime will be required. For partially weathered pyritic spoils, standard tests may indicate large lime requirements. Yet, even after the addition of lime, these materials may revert to acid conditions because the unweathered pyritic materials continue to oxidize.

Tests are available for ascertaining the maximum amount of acid (potential acidity) that might be produced by a completely weathered rock or minesoil. In one test that works well on eastern minesoils, the pyritic sulfur content is estimated from the total sulfur content of the minesoil sample after the sample is leached to remove sulfates.

Application of the full amount of lime indicated by the potential acidity test will reduce the chances that the minesoil will again become extremely acid. One drawback of these tests is that inert and slowly oxidizable forms of pyrite also may be measured and regarded as potentially acid forming; thus, for some minesoils, more lime might be recommended than is necessary to adequately amend the potentially active acidity.

Testing for potential acidity is recommended on fresh, unweathered minesoils that are suspected of becoming extremely acid as they weather. This test also is recommended on some partially weathered minesoils that are already extremely acid and show indications of continuing to be acid for many years.

Phosphorus

Testing soils for plant-available phosphorus (P) usually is recommended because P often is deficient or unavailable to plants. Several methods are available for determining plant-available P in soils; but not all methods give meaningful results in spoils or minesoils, nor is any one method necessarily best for testing all types of minesoils. For example, an extracting method known as the Bray #1 has given meaningful results on many of the minesoils derived from rocks of Pennsylvanian Age, but several other standard agricultural tests did not give meaningful results. Thus, results of soil tests for P should be accepted only if the soil-testing facility can show that the tests are meaningful for the minesoil materials being tested. To be meaningful, the results of the tests should indicate accurately (correlate with) the response of plants to that nutrient when added to the soil being tested.

Potassium

Most standard soil tests for potassium (K) give values that are reasonably meaningful when used on minesoils. However, fertilizer experiments on minesoils generally have shown little or no increase in plant yield due to application of potassium fertilizer. Thus, soil testing for K may be of little benefit except for areas designated for production of agricultural crops.

Other Tests

Normally, additional soil tests are not needed for determining the plantability and treatment of reconstructed soils and minesoils. Exceptions may be where unusual toxicity problems are encountered, such as with boron, selenium, or other minor elements. Tests for soil nitrogen have value mainly for replaced topsoil to be used for cropland purposes. In minesoils, their value is limited because much of the nitrogen present is not biologically available. Also, nitrogen usually is deficient in minesoils and nitrogen fertilization is recommended as a standard practice.

Other soil tests can be made, but because the geology, chemistry, and physics of minesoils are so complex and varied, these tests may have value only where meaningful interpretations of them have been developed for the particular soils being revegetated.

HANDLING OF PLANT-GROWTH MEDIA

The goal of soil reconstruction is to create a soil that is as deep and as favorable to root growth as is necessary to achieve the productivity standard established in the PAP. Proper handling of soil and geologic strata is extremely important to the successful revegetation of reconstructed soils on surface-mined land. Errors made in soil handling such as excessive compaction may be nearly impossible to correct.

The special handling requirements for soils on prime farmlands are presented in a separate section of this handbook entitled Special Considerations.

Removal

It is important that the topsoil be removed from the land in a separate layer and replaced on the backfill area, or if not used immediately, segregated in a separate stockpile from other spoil. Stockpiles should be protected from erosion and from being contaminated by acid or toxic material, and the topsoil should be maintained in a usable condition for sustaining vegetation when restored during reclamation. Where topsoil is of insufficient quantity or of poor quality for sustaining vegetation, or where other strata can be shown to be more suitable for vegetation requirements, such other strata that are best able to support vegetation can be used and should be removed, segregated, and preserved in a like manner as the topsoil.

To meet the success standards required by the approved State regulatory program, the operator may need to reconstruct soils with rooting depths as deep as the normal soils of the permit area. To achieve this the operator may need to remove and stockpile separately all soil horizons to have suitable rooting-depth material available for soil reconstruction.

Methods

There are several kinds of equipment available to remove the topsoil and other soil layers. These include scrapers, dozers, draglines, excavating wheels, front-end loaders, and road graders. The machine selected should provide the least damage to soil structures and pore space and still allow effective segregation of soil layers during the soil removal process.

Timing

Topsoil and other soil horizons or geologic strata should be removed after the vegetative cover that would interfere with its salvage is cleared from the area. The soil should be removed before any drilling, blasting, mining, or other surface disturbance.

Removal of soils when they are dry or when the moisture content is less than 75 percent of optimum (Standard Proctor Test) will help preserve soil structure, reduce compaction, and reduce loss of pore space. The optimum moisture content for plant growth is close to ⅓ bar ten-