



United States  
Department of  
Agriculture

Forest Service

**Northeastern Forest  
Experiment Station**

General Technical  
Report NE-68

1981



# **A Guide for Revegetating Coal Minesoils in the Eastern United States**

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## ABSTRACT

This report provides information, recommendations, and guidelines for revegetating land in the Eastern United States that has been disturbed by coal mining. Included are brief descriptions of major coal mining regions in the East, and a discussion of minesoil properties and procedures for sampling testing, and amending minesoils. Plant species that have been used for revegetating surface-mined lands are identified and described. Selection criteria for plant species and methods and requirements for seeding and planting are explained. Some of the data on tree species used in reforestation were obtained from recent surveys of 30-year-old experimental plantings in several Eastern States.

## FOREWORD

The mining of coal, especially surface mining, often is dangerous to environmental resources. Existing vegetation is destroyed, ecosystems are altered, and unreclaimed areas are visually displeasing. One of the adverse effects of mining and vegetation removal is the degradation and pollution of water resources. Erosion on raw exposed minesoils can contribute large quantities of sediment to streams. Where the overburden contains acid-bearing rocks, streams also are polluted with toxic chemical substances.

The revegetation of land disturbed by coal mining is necessary primarily for controlling runoff, erosion, and sedimentation. Simultaneously, the establishment of vegetation improves the visual quality of mined areas and aids in or contributes directly to restoring mined land to productive uses.

The principles and guidelines in this report are applicable primarily to past and current surface-mining operations; they may also apply to surface disturbances caused by underground mining. This report is not directed to the establishment of agricultural crops on areas designated as "prime farmland," though many of the revegetation principles and practices will apply.

This study was made possible by funding from the U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, Ohio, and was completed under Contract No. EPA-IAG-DE-E764 by the U.S. Department of Agriculture Forest Service, Northeastern Forest Experiment Station, Broomall, Pa.

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## ACKNOWLEDGMENTS

Grateful acknowledgment is expressed to Rufus Allen, Walter Davidson, Tom Despard, and Bernard Slick of the USDA Forest Service, Northeastern Fore Experiment Station, for their help in preparing portions of the text. Thanks are also due to reviewers of the manuscript and others who willingly contributed advice and additional information, especially Tom Zarger, Tennessee Valley Authority; Bill Berg, Colorado State University; John Sencindiver, West Virginia University; Sam Lyle, Auburn University; Scott Brundage, Peabody Coal Company; Michael Morin, Illinois Department of Conservation; Steve Clubine, Missouri Department of Conservation; Elmore Grim, Kentucky Department for Natural Resources and Environmental Protection; George Holmberg and Wayne Everett, U.S. Soil Conservation Service; Chuck Wolf, U.S. Office of Surface Mining; and Willie Curtis and William Plass, Forest Service.

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## SECTION 3

### MINESOILS

#### PROPERTIES THAT AFFECT VEGETATION ESTABLISHMENT

Minesoils, also called spoils, are the geologic materials that, in surface mining, are removed from above beds of coal. The amounts of the different geologic materials and the manner in which they are handled and mixed during mining and grading directly affect the chemical, physical, mineralogical, and biological properties or characteristics of minesoils. These properties can affect plant growth and should be identified before planting, even where topsoil is reapplied. This knowledge is especially needed for identifying and treating those minesoils with properties that limit or prevent the establishment and growth of vegetation. Ideally, this knowledge also can be helpful in selecting plant species that are best suited or adapted to specific sites or minesoil conditions, especially where the site cannot be changed to suit a given species.

#### Chemical Properties

The chemical properties of minesoils that are of most concern in revegetation are chemical reaction (pH), acid-induced toxicities, and nutrient deficiencies.

#### Soil Reaction (Acidity or Alkalinity)--

Soil reaction is the degree or intensity of soil acidity or soil alkalinity expressed as pH. The pH scale ranges from 0 to 14. A pH of 7 is neutral in reaction; lower values indicate acidity and higher values indicate alkalinity. The pH scale is logarithmic, i.e., the intensity of acidity or alkalinity changes tenfold with each unit change in pH. For example, a pH of 4.0 is 10 times more acid than a pH of 5.0 and a pH of 3.0 is 100 times more acid than a pH of 5.0.

Soil reaction (pH) is probably the most useful criterion for predicting the capacity of minesoil to support vegetation. Not only is plant growth affected by pH, but inferences can also be made about other qualities. For example, the availability of some plant nutrients is limited in both extremely acid and strongly alkaline soils, but these nutrients are available to plants in soils that are moderately acid to slightly alkaline.

Minesoils in the East are mostly in the acid range (pH below 7.0), though some are mildly to moderately alkaline (pH 7.0 to 8.5). Problems with revege-

tating the alkaline minesoils are few. Problems with revegetating acid minesoils are more common, especially those that are extremely acid (pH 4.0 and lower). Oxidation of iron sulfides found in the coal and overburden strata is the primary cause of extremely acid and toxic minesoils.

Some plant species are more tolerant of acid conditions than others. Therefore, by knowing the pH of a minesoil, species tolerant of a given pH range can be selected for revegetation purposes. As a general rule, most plant species will grow in minesoil with a pH higher than 5.5. A more limited number will grow in the pH range 4.6 to 5.5. Even fewer species of plants can tolerate minesoil pH below 4.5, and only a very few will grow where pH is below 4.0 (Figure 3). However, these limits can vary in different minesoils depending on the chemical and physical characteristics of the rock constituents of each minesoil.

A pH reading on minesoil also can indicate where an amendment such as lime is needed to neutralize acidity. On some acid minesoils, attempting to establish acid-tolerant plants may be more practical than decreasing acidity with amendments; but on extremely acid minesoils there is no choice. Lime or

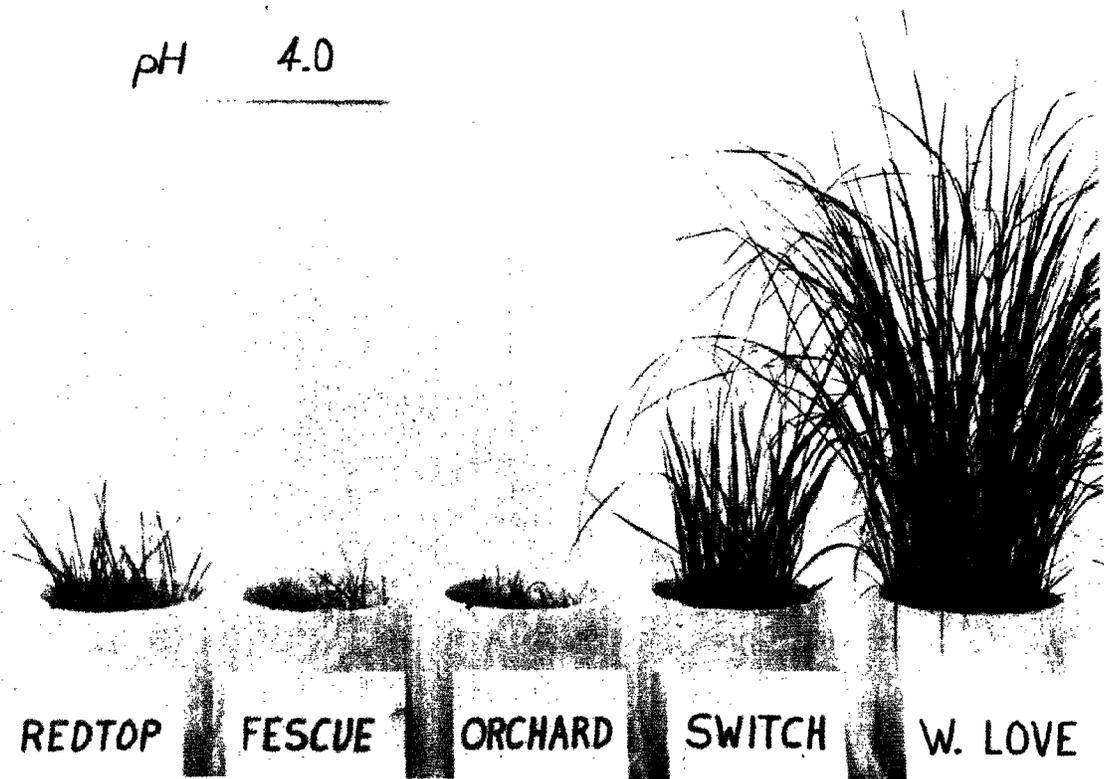


Figure 3. Weeping lovegrass--one of the more acid-tolerant plant species.

some other treatment must be applied to lower or neutralize the acidity if plants are expected to grow. Details on liming and other amendments are presented in Section 5.

Sampling and analyzing overburden strata before mining begins provide an opportunity to predict and prevent problems associated with acid minesoils. Procedures for covering or blending acid-producing materials with nonacid overburden materials or topsoil should be incorporated in the mining operation.

#### Acid-Induced Toxicities--

Although pH is an indicator for assessing acidity and predicting plantability of minesoils, it does not always explain all of the chemical problems that can be associated with revegetating a particular site. An imbalance of elements, an excess of one element, or a high level of dissolved solids (salts) can be more deleterious to plant growth than acidity itself. For example, elements such as aluminum, iron, manganese, copper, nickel, and zinc that are present in some minesoils become increasingly soluble as the pH decreases below 5.5. When the concentration of these elements exceeds certain levels in the soil solution, they become toxic to plants and interfere with establishment and growth. The concentration of these toxic elements is greater in some geologic materials than in others; therefore, different minesoils, even with the same pH, may not have the same effect on plant growth. Plants may grow satisfactorily in one minesoil with a pH of 4.5 but not grow at all in others with the same pH. Thus, plant species cannot be assigned definite pH tolerance limits that are correct for all minesoils.

Aluminum and manganese are the elements found most often in concentrations toxic to plants. The primary effect of aluminum toxicity is to reduce or inhibit root growth. Manganese toxicity results primarily in reduced shoot growth. In legumes, symptoms of manganese toxicity are expressed by chlorosis (yellowing) of leaf margins sometimes coincident with rust-colored spots on the leaflets.

A recommended practice for treating acid minesoil is to raise the pH to 5.5 or higher by applying lime. At pH 5.5 most of the toxic elements will be precipitated from the soil solution and will no longer have harmful effects on plants.

#### Nutrient Deficiencies--

Minesoils most often are deficient in nitrogen and phosphorus (Figure 4). Nitrogen is nearly always deficient, especially where topsoil and associated organic materials were removed and buried during mining. Establishment of herbaceous vegetation is always hastened by the application of nitrogen fertilizer.

Plant-available phosphorus is adequate in some overburden materials, but more often it is deficient. Reasons for phosphorus deficiency include: (1) the overburden materials may contain only small amounts of phosphorus-bearing minerals; (2) the phosphorus compounds that are present are insoluble,

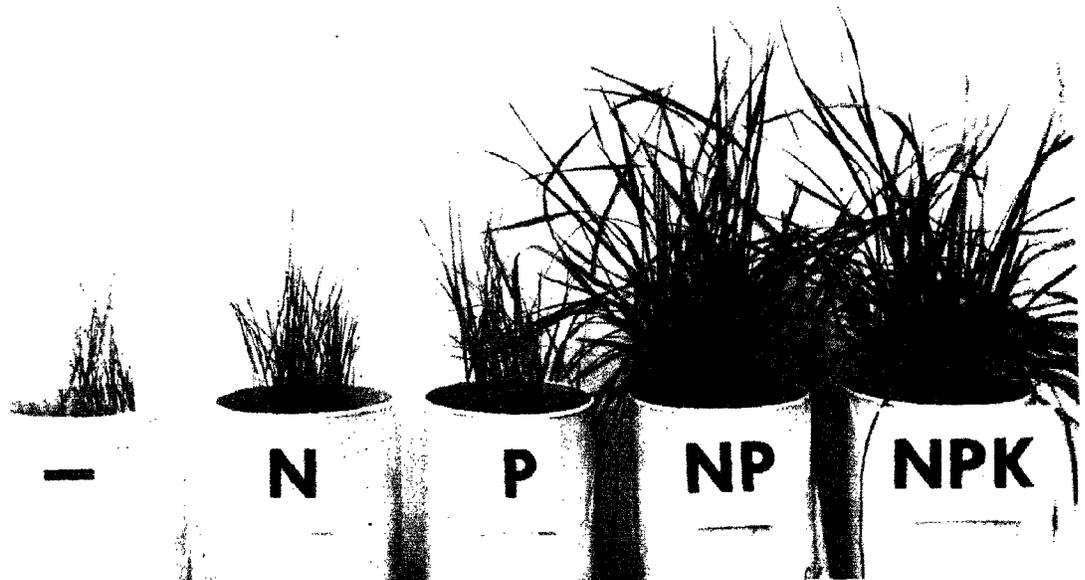


Figure 4. Response of vegetation to Nitrogen (N) and Phosphorus (P) fertilizer typical on most minesoils.

especially in very acid and alkaline materials; (3) there is no reservoir of organic phosphorus compounds. Application of phosphorus fertilizer is necessary on minesoils deficient in phosphorus, and it usually hastens the establishment of herbaceous cover even on minesoils that contain plant-available phosphorus in amounts adequate for plant growth.

Plant-available potassium is adequate for plant establishment in most coal minesoils because clay minerals, micas, and some feldspars that constitute a source of potassium usually are present in the overburden materials. Thus, the use of potassium fertilizer usually is not needed to establish vegetation. However, where vegetation is repeatedly harvested and removed, fertilization with potassium may subsequently become necessary. Similarly, potassium levels may in time be reduced by natural weathering and leaching.

Undoubtedly, there are deficiencies of other nutrients on some minesoils, but most of these have not yet been defined by researchers. It is known that on some minesoils, imbalances between calcium and magnesium hinder the establishment and vigorous growth of vegetation.

#### Physical Properties

Physical properties of minesoils such as stoniness, distribution of particle sizes, bulk density, slope angle, length of slope, color, aspect,

erodibility, and stability can influence the selection, establishment, and growth of vegetation. Some of these properties are difficult to change, whereas others can be altered by earth moving and grading. The adverse effects related to some properties such as dark color and aspect can be altered by mulching the surface. Often, though, adverse physical problems are accepted with the hope that natural weathering processes and vegetation will eventually alter and improve these conditions.

As with chemical problems, the best solution to physical problems is to prevent them. A preliminary analysis of the overburden could be beneficial in determining how to separate or mix different rock materials during mining and grading so that the materials left on and near the surface will have acceptable physical properties. Replacing topsoil on some areas may improve the physical qualities of the reclaimed surface for plant growth. But in other situations, replacing topsoil may result in a compacted surface with increased potential for erosion.

#### Stoniness--

Stones and boulders on and near the surface curtail the use of tillage, planting, and seeding equipment. An abundance of stones may influence the choice of species used, especially trees. On extremely stony areas, direct seeding of trees may be more feasible than hand planting seedlings; the choice of tree species is limited then to tree species that can be successfully established by direct seeding.

#### Particle-Size Distribution--

Particle-size distribution refers to the relative amount or proportion of the various sizes of particles in the whole soil, including sand, silt, clay, and rock fragments. It affects water relations (drainage and water-holding capacity), soil structure, bulk density, erodibility, cation exchange capacity, and workability of the minesoil. Minesoils with predominantly coarse particles dry out quickly, especially at the surface where moisture for seed germination and seedling establishment is most critical. With a high proportion of fine particles, especially clays, minesoils can be plastic when wet and very hard when dry. In minesoils with no adverse chemical characteristics, plant growth is usually most favored where there are near-equal proportions of fine (less than 2 mm) and coarse materials.

#### Bulk Density--

Bulk density is the weight of a unit volume of dry soil, ordinarily expressed as grams per cubic centimeter. This volume includes both soil solids and pore spaces. Soils that are loose and porous have low bulk density; those that are densely structured or compacted, high in clay content, and nonporous have high bulk density. The size and volume of pores are important to plant growth because they influence the movement of water and air in the soil. The bulk density of minesoils is related mostly to the types and amounts of the geologic and soil constituents and the proportions of different particle sizes. Excessive movement and compaction by grading and soil-moving equipment also can affect bulk density of minesoils.

## Slope--

Steepness of slope influences vegetation establishment and land use. Long and steep slopes normally erode more rapidly and are more difficult to vegetate than gentle slopes, short slopes, and level areas. Establishing vegetation near the lower end of long steep slopes can be especially difficult. Probable causes for this difficulty include failure or inability to apply seed and fertilizer on lower slopes, greater erosion and deposition on lower than on upper slopes, and a concentration of larger rocks and coarse material near the bottom of the slopes.

Long slopes erode more severely than short ones because the velocity of runoff water increases as the length of the slope increases. Thus, gully erosion usually is greater on lower than on upper portions of slopes. The elimination of highwalls in mountainous areas may create long steep slopes that increase the potential for accelerated runoff and erosion. Where feasible, the formation of long slopes should be avoided. Where slopes must be long, they should be interrupted with terraces or benches that drain on a 1- to 2-percent grade to a stable outlet or waterway.

## Erosion Potential--

As discussed in relation to long slopes, erosion is often the most disruptive of physical factors in establishing vegetation. Obviously, steep slopes have greater potential to erode than level benches or gentle slopes. Minesoils containing a large amount of fine particles normally erode more than those consisting of coarser materials. Stony minesoils are less subject to erosion damage than nonstony ones, but for other reasons they may be more difficult to vegetate.

A quickly established cover of vegetation helps retard erosion and is especially effective in controlling surface or sheet erosion. But on some areas other treatments are needed to help retard erosion, especially gully erosion. The use of mulches or soil stabilizers and mechanical structures such as terraces and contour furrows are helpful in reducing erosion until vegetation is established.

## Color--

Dark colors absorb more heat from the sun's rays than light colors. Thus, on black or dark-colored minesoils, the surface temperature can reach levels that are lethal to seedlings. This may occur especially during summer periods, and on south and west exposures. High temperatures also cause soils to dry out more rapidly.

Color can be a clue to chemical characteristics. For example, sandstone with brown interior color is weathered and will not be toxic to plants. Sandstone with gray interior color is unweathered and may be toxic to plants because it may contain unoxidized pyrite. Black shales often are acid and toxic-forming, and should be buried under nontoxic material or topsoil. Occasionally, dark-colored materials are not acid and chemically are the best overburden material available for plant growth. In such cases, the material

should remain on the surface and be mulched or, if possible, lightly covered or blended with topsoil or light-colored spoil material.

#### Aspect--

Aspect, the direction that a slope faces, can affect the establishment and, thus, the selection of vegetation for mined areas. South- and west-facing slopes normally are hotter and dryer than north- and east-facing slopes. Some plant species are better adapted to south aspects than other species. For example, pine trees usually thrive better than most hardwood trees on south slopes. Mulching to help establish vegetation is usually more beneficial on south and west aspects than on north and east ones.

#### Biological Properties

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

#### Microorganisms--

Minesoils are not completely sterile. They contain bacteria, fungi, and actinomycetes, but the kinds and numbers of these organisms in unvegetated minesoil are few compared with those in agricultural and forest soils. However, as vegetation becomes established, the populations of some of these organisms will increase by natural processes. Other types may need to be artificially introduced. Some microorganisms are symbiotic, which means that they give to and derive benefit from the plants on which they live. For example, *Rhizobium* bacteria live on the roots of legumes and take nitrogen from the air and fix it in nodules for use by the host plant. Similarly, most species of plants have mycorrhizal associations that involve root-inhabiting fungi and plant feeder roots and increase the plant's ability to take up nutrients, especially phosphorus. Mycorrhizal associations are beneficial to the survival and growth of most plants.

#### Soil Fauna--

Soil fauna are the worms, beetles, bugs, and similar soil-dwelling creatures that are primarily responsible for consuming and altering organic materials such as plant litter, and burying or mixing it in the soil. New minesoils normally are devoid of soil fauna. Their presence becomes most important after vegetation is well established and plant litter begins to accumulate. However, natural reestablishment of soil fauna populations is relatively slow. Most soil fauna are not highly mobile, so several to many years may be required for a mined area to be repopulated by the natural movement of fauna from populations in adjacent undisturbed lands. Obviously, narrow strips of revegetated minesoils will repopulate sooner than large broad areas. Artificial introduction of soil fauna is possible and has proven beneficial

in small experimental plots, but its practicality has not been demonstrated on large areas. Immediate replacement of topsoil is probably the most promising means of reestablishing soil fauna on mined sites.

## SOIL REPLACEMENT

Replacement of the A horizon of native soils on surface-mined areas will generally have beneficial effects on the establishment of vegetation, especially where proper techniques are used for soil reconstruction. For example, in areas such as northern Illinois, the native prairie soils are thick and relatively fertile. Where surface mined, many of these areas are regulated as prime farmlands and the soils are reconstructed under special provisions of the Federal Surface Mining Control and Reclamation Act of 1977.

In other mining areas, there is evidence that substitute materials are equal to or better than the A horizon as a plant growth media. In areas such as the mountainous parts of the Appalachian Region, soils often are thin, highly leached, and relatively infertile. Replacing these soils may not always enhance the establishment and productivity of vegetation on mined areas.

The primary benefit of replacing soil is to improve the quality of plant growth medium on areas where the spoils or minesoils are chemically and physically less desirable than the native soils. Usually, soil replacement will create a fairly uniform surface condition over the entire area with few or no rocks to interfere with tillage, planting, and seeding. Another probable benefit of soil replacement, especially of the surface or A horizon, is the potential source of soil fauna and microorganisms such as endomycorrhizal fungi. Where reforestation and wildlife habitat are planned postmining land uses, the presence of seed, rhizomes, or other plant parts in the replaced soil may be of benefit in aiding or hastening the reestablishment of native vegetation. Immediate replacement of soil is most beneficial because populations of many of the biological organisms are reduced or destroyed by long-term storage or stockpiling of soil.

Detrimental effects of soil replacement can occur on areas where covering soils have chemical and physical properties that are less desirable than those of the spoils that will be covered. Where improperly handled, the replaced soil will be compacted and physically degraded by earth-moving equipment. Replaced soils, too, may erode more easily than some spoil materials. Unless scarified or otherwise treated, a barrier to root penetration is sometimes created at the interface between the replaced soil and the covered spoils. Soils may sometimes contain seed of unwanted plant species that compete with the planted species.

In some mining regions, especially in the mountains of Appalachia, there usually is very little topsoil (A horizon) that can be saved for replacement on mined areas. Often, most of the "soil" that is saved and replaced consists of B and C horizons or parent material. This material usually is low in plant nutrients, and often is strongly acid and contains relatively high amounts of exchangeable aluminum. The B- and C-horizon materials often contain a high proportion of silt and clay particles that are easily compacted into a dense,

slowly permeable layer by heavy earth-moving equipment, especially when wet soil is moved. In some areas, these horizons have a large proportion of coarse fragments. Because one benefit of saving and replacing soil may be derived from its biologic and organic components, mixing or blending the soil into the surface layer of spoil could in some cases be more beneficial to the establishment of vegetation than spreading it on the surface of the mined area.

## SAMPLING AND TESTING MINESOILS

Knowledge of minesoil properties normally 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 vegetation establishment. This section discusses sampling procedures and soil tests used for analyzing minesoils, including reasons why the tests are useful and some of their limitations.

### Minesoil 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 sampled 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 to 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 minesoil. 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 should be included in 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 minesoil 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 minesoil in the area from which it is collected.

To describe and map an area in more 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 in time and money for collecting and in 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 would increase costs. Some States 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 1/2-inch in diameter. If a composite sample is being collected, place this slice 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 container and label the containers.

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 the samples in the containers recommended or supplied by your testing agency. The State soil test laboratory in some States provides minesoil testing services either directly or through county extension agents. In some 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, minesoils offer a potential rooting depth exceeding that on the undisturbed native soils. Such minesoils, 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 minesoils 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. For in the process of grading off several feet of spoil, other materials may be uncovered and exposed that have chemical and physical properties which 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 with a 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 decision to change plant types or species may be required.

### Soil Tests

Many kinds of soil tests can be made on minesoils, but for most revegetation jobs, only a few tests are needed to determine the plantability of the minesoil and prescribe the required amendments. Those tests considered most useful are discussed below.

#### pH--

Tests for pH are most frequently used for assessing acidity or alkalinity and predicting plantability of minesoil. A pH meter is the standard device for measuring soil pH because it is the most accurate. A common practice is to collect samples of minesoil 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 is required, and that containers, distilled water, and buffer solutions must be transported.

Several types of field kits and other devices are available for measuring pH of soil. However, some of these do not give accurate readings on all minesoils when compared with the pH meter. Field kits, such as the LaMotte-Morgan, that use several pH indicator dyes agreed closely with the pH meter. Some field kits that use only one indicator dye are less accurate. Therefore, 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.

#### Lime Requirements--

The pH readings indicate where problems with minesoil acidity or alkalinity may be encountered. However, 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 mine-soil 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 minesoils. It is a fast, routine test developed for acid soils that contain appreciable amounts of

exchangeable aluminum. The test is useful for acid minesoils because aluminum is often the major exchangeable cation contributing to total exchangeable acidity.

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 that shows 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.

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 eastern Kentucky minesoils is: Apply 2,000 pounds per acre of  $\text{CaCO}_3$  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, and 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 show requirements for large amounts of lime. Yet, even after the addition of lime, these materials may revert to acid conditions because the pyritic materials continue to oxidize.

Several tests are available at some soil testing labs for ascertaining the maximum amount of acid (potential acidity) that might be produced by a completely weathered rock or minesoil. In one test, the pyritic sulfur content is estimated from the total sulfur content of the minesoil sample after the sample is leached to remove sulfates.

A more direct measure of total potential acidity includes the use of hydrogen peroxide to oxidize the reactive pyrite in the minesoil sample. The amount of released acid is determined by titration to neutrality with a standard base.

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 mine-soils that are suspected of becoming extremely acid as they weather. This test is also recommended on some partially weathered mine-soils that are already extremely acid and show indications of continuing to be acid for many years. Often, these mine-soils contain large amounts of fine-grained pyrites that, with normal weathering, will continue to oxidize for several years.

#### Phosphorus--

Testing mine-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 mine-soils, nor is any one method necessarily best for testing all types of mine-soils. For example, an extracting method known as the Bray #1 has given meaningful results on many of the mine-soils 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 mine-soil materials being tested.

#### Potassium--

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

#### Other Tests--

Normally, additional soil tests are not needed for determining the plant-ability and treatment of mine-soils. Exceptions may be where unusual toxicity problems are encountered such as with boron or other minor elements. Most soil nitrogen tests have limited value because much of the nitrogen present in mine-soils is not biologically available. Also, nitrogen is nearly always deficient in mine-soils and nitrogen fertilization is recommended as a standard practice.

Other soil tests can be made, but because the geology, chemistry, and physics of mine-soils are so complex and varied, these tests may have value only where meaningful interpretations of them have been developed for the mine-soils being revegetated. To be meaningful, the results of a soil test should correlate with the response of plants growing in the soil being tested.