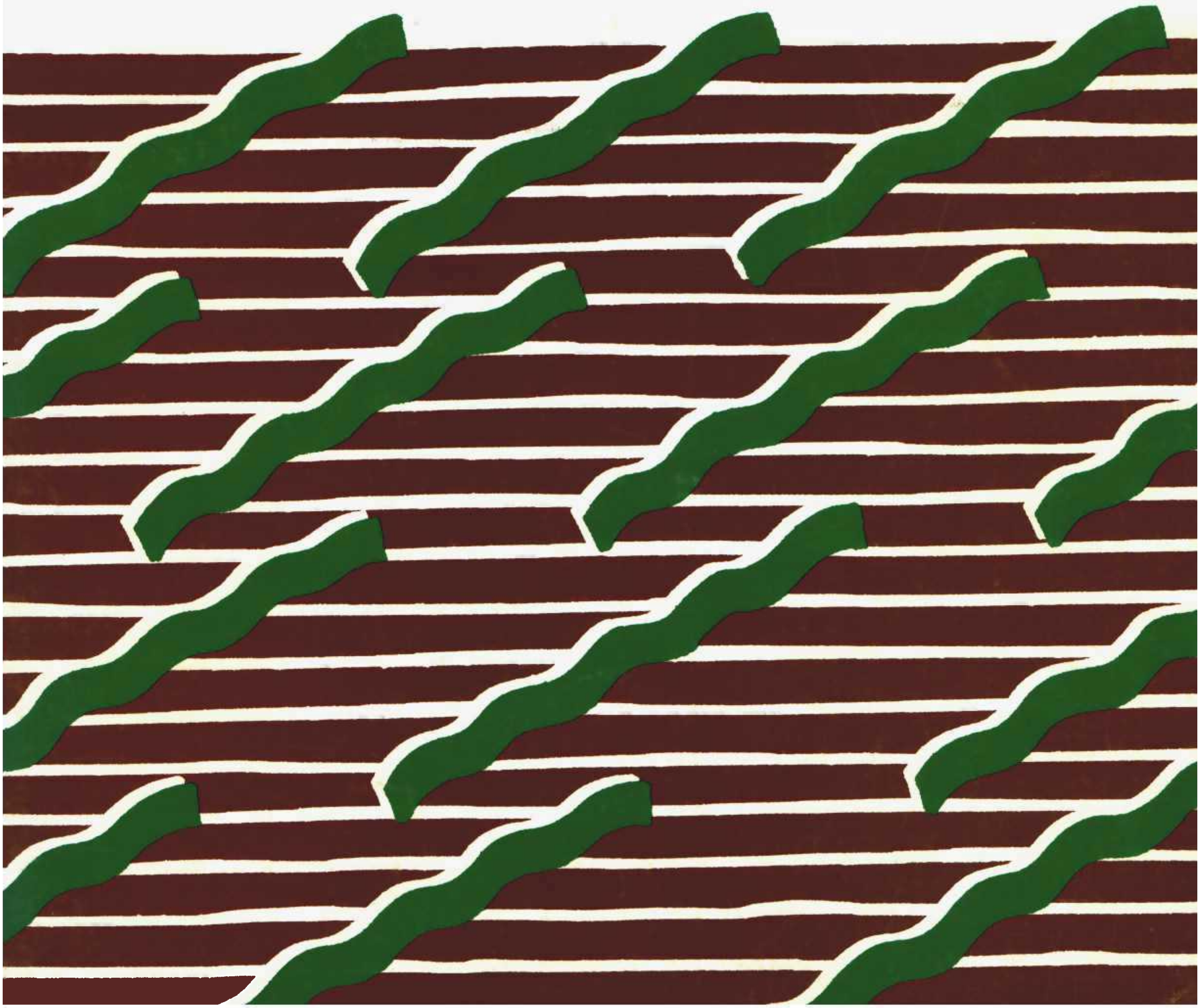
A MANUAL FOR TRAINING RECLAMATION INSPECTORS IN THE FUNDAMENTALS OF SOILS AND REVEGETATION

By Willis G. Vogel

Prepared for the
Office of Surface Mining
and Enforcement
by the
U.S. Department
of Agriculture,
Forest Service



This page intentionally left blank.

A MANUAL FOR TRAINING RECLAMATION INSPECTORS IN THE FUNDAMENTALS OF SOILS AND REVEGETATION

By Willis G. Vogel

U.S. Department of Agriculture
Northeastern Forest Experiment Station
1835 Big Hill Road
Berea, Kentucky 40403

Produced for the Office of Surface
Mining and Enforcement by the
Soil and Water Conservation Society
7515 Northeast Ankeny Road
Ankeny, Iowa 50021-9764
September 1987

This page intentionally left blank.

Contents

Figures

Tables

Acknowledgments

This handbook was prepared by personnel of the Northeastern Forest Experiment Station's Surface Mine Reclamation Research Project in Berea, Kentucky. Its development was made possible by funding from the Office of Surface Mining, U. S. Department of the Interior.

Contributions to the preparation of this handbook by the following people are gratefully acknowledged: Frederick M. Rothwell, Kenneth L. Dyer (retired), Walter H. Davidson, and Gary L. Wade, USDA Forest Service, Northeastern Forest Experiment Station, Berea, Kentucky; Samuel Petitto, USDI Office of Surface Mining; Allen Hidlebaugh (retired), USDA Soil Conservation Service; Rodney A. Moore, USDI Office of Surface Mining, Morgantown, West Virginia; Arlo Dalrymple, USDI Office of Surface Mining, Washington, D.C.; Edith B. Allen, Dennis F. Fransway, Robert E. Kirmse, James N. Long, and David W. Roberts, all from Utah State University, Department of Forest Resources; and Ronald R. Ries, USDA Agricultural Research Service.

Much of the information was gathered from existing revegetation guides, manuals, handbooks, textbooks, and other materials published by federal and state agencies, universities, colleges, experiment stations, and the mining industry; and from firsthand knowledge and experience of the various authors. References from which information was gathered are listed in the bibliography.

Foreword

The purpose of this handbook is to give surface mining and reclamation inspectors a basic knowledge and understanding of soils and vegetation as they relate to surface mining and reclamation. It is not meant to be a detailed treatment of all revegetation situations, but to provide guidance in understanding and adapting principles and practices of soil and plant sciences appropriate to overburden and soil removal, replacement, testing, and treatment; selecting and using species for various conditions and land uses; and evaluating revegetation success. The handbook can be used in the training of surface mining and reclamation inspectors, both Federal and State, and as a reference for inspectors in carrying out their assigned duties.

This handbook was assembled and edited by personnel of the USDA Forest Service, Northeastern Forest Experiment Station Surface Mine Reclamation Research Project, and Northeastern Area State and Private Forestry, at Berea, Kentucky. Active and retired personnel from the Berea Research Project, USDA Soil Conservation Service, Utah State University, North Dakota State University, and USDA Agricultural Research Service contributed various sections to the handbook. Its development was made possible by funding from the Office of Surface Mining, U.S. Department of the Interior.

This page intentionally left blank.

THE PERMIT APPLICATION PACKAGE

A review of the topsoil and revegetation specifications contained in the Permit Application Package (PAP) will provide the inspector with information on how the operator plans to remove, store, and redistribute topsoil, and how vegetation will be established, maintained, and evaluated. Where this information is compared with on-site conditions as part of a premining inspection, the inspector can make a number of judgments about the suitability of the specifications and the resulting postmining land use.

Thorough review of the PAP soils and revegetation specifications will provide information such as:

- Location of topsoil storage areas.
- Protective measures for stored topsoil.
- Methods and timing of topsoil redistribution.
- Soil tests for determining lime and fertilizer requirements.
- Herbaceous species, seeding rates, and methods.
- Woody species, planting densities and methods.
- Use of temporary cover for erosion control.
- Mulch application, rates, and methods.
- Other information on vegetation and postmining land uses.
- Criteria for measuring revegetation success.

A thorough knowledge of the plan will help the inspector visualize the reclamation process and expedite the on-site inspection. For example, this information may be useful during an inspection to determine if an operator is contaminating topsoil or failing to store the required amount of topsoil. The plan should detail how the topsoil will be protected from wind and water erosion and contaminants. Measures may range from mulching to covering with plastic. Procedures for redistributing topsoil on the backfilled area should be detailed in the plan. Also, the PAP usually describes the equipment to be used in topsoil removal, storage, and redistribution.

Information concerning soil testing methods and soil amendments is an important part of the PAP. Needed soil amendments such as lime, nitrogen (N), phosphorus (P), and potassium (K) are listed and rates of application (usually in pounds/acre), based on soil tests, are given. Methods for application and incorporation of these soil amendments are detailed and described. Methods for clearing, grubbing, and disposing of debris, if applicable, should be defined in the permit.

The permit must specify the success standards that will be used to determine whether or not cover and other vegetative criteria are adequate for bond release. Depending on geographic region and the particular regulatory program, revegetation success will be measured against either reference areas or performance standards. Reference areas, usually undisturbed plots typical of the soils, topography, and vegetation of the area, are sometimes used as the basis for comparing the vegetative cover, productivity, and other parameters on the revegetated mine site. Technical performance standards specify the percent ground cover, maximum size of bare-areas productivity, or other constraints to be met on the revegetated area.

While reviewing the PAP soils and revegetation information, it is essential to consider the existing and proposed hydrologic characteristics of the mine and adjacent areas. In some instances, mining will reduce or change water availability schemes and consequently modify expectations of success compared to premining conditions. During the field review portion of the inspection, attention should be focused on the differences between proposed or anticipated resoiling and revegetation activities and the actual implementation and early performance and effectiveness of the activities.

In preparing for the field inspection and documenting report, the inspector should reduce the PAP information to a short but concise set of notes that might include:

Topsoil

- Type survey (SCS-county-site specific) to determine confidence level.
- Special characteristics and handling methods for prime farmland.
- General characteristics of the major soils for later visual review, i.e. depths, color, dominant soils names.
- General distribution of major or soil components as shown on soils map—consider erodibility and slopes.
- Timing and sequence of removal of topsoil or other materials to be segregated.
- Preparation of ground prior to redistribution of topsoil, i.e., scarification or liming.
- Redistribution of topsoil to avoid overcompaction and achieve uniform depth.
- Location of topsoil storage areas and type of protection.
- Soil testing to be done prior to revegetation efforts.
- Types and amounts of fertilizers or other soil amendments proposed.
- Approval for mixed overburdens or topsoil substitutes for the site.

Revegetation

- Type, seeding period, and methods for temporary and permanent cover seedings.
- Mulching practices to be observed.
- General or specific measures for area stabilization.
- Proper timing for seeding and planting of species and use of in situ mulch.
- Compatibility of species with surrounding area and proposed postmining land use.

Geology and Hydrology

- Location and nature of reference areas.
- Appropriate success standards for bond releases.
- General subsoil and overburden characteristics associated with the mine area.
- General subsurface flow and estimated impact of mining indicated in the probable hydrologic consequences (PHC).

Where a premining inspection of the site is made, the inspector can gain valuable insight about the suitability of the proposed postmining land use in relation to the premining land use. Soil type, slope, aspect, and the type and vigor of indigenous vegetation all provide clues to land productivity and the suitability of the proposed postmining land use. The approved permit can then be used through the life of the mine to ensure proper reclamation.

The inspector will want to prepare for the field review by accumulating a few essential pieces of equipment to be carried when away from the vehicle. At a minimum, the items should include:

- A camera and extra film.
- A segmented soil probe.
- An individual soil sample (pH indicator) kit.
- Several self-sealing plastic bags (approximately 12 inches × 12 inches).
- A 12-foot retractable tape measure.
- A note pad.

These items and the notes compiled during the PAP review should be supplemented with the soil survey maps for the site or portion of the site to be checked. Upon arrival at the mine site and attending to the routine procedural matters, the inspector can begin his or her ambulatory inspection of the soils and revegetation aspects of the operation.

Because sites and areas usually are quite different, the particulars of the inspection will vary greatly. However, most surface coal mining and reclamation operations usually will have three distinct areas:

- The undisturbed portion.
- The active mining portion in various phases of mining and reclamation.
- The reclaimed portion.

When operations have all three areas, primary attention should be given to the removal, storage, and redistribution of the topsoil. Each element in the process is fundamentally aimed at preventing soil loss and deterioration and should be reviewed with that perspective. Mismanagement of topsoil operations are indicated by:

- Lack of appropriate equipment on the site to remove or redistribute topsoil according to approved plans.
- Significant bare and pit areas with no existing topsoil stockpiles.
- Topsoil pushed or blown into pits or downslopes.
- Drill holes for explosives in grass covered areas of original ground.
- Topsoil in spoil areas or fill constructions.
- Unprotected topsoil piles with signs of erosion or contamination.
- Extensive tire marks or signs of compaction on retopsoiled areas.
- Unrevegetated areas with wind or water erosion.
- Topsoil being redistributed on unprepared spoil or subsoil base.
- Obvious lack of uniformity in redistribution of topsoil indicated by bare spots or exposed spoil (conduct a few test probes of retopsoil areas and measure depths).
- Topsoiled areas not graded in accordance with approximate original contour (AOC) or other plans, or with exposed coal or waste materials.

Being satisfied that topsoil has been removed, handled, and replaced satisfactorily, the inspector should turn his or her attention to areas that have been seeded and mulched. Procedures to determine the implementation of proper seeding and mulching practices include:

- Observe on-going seeding and mulching operations, including a look at the evidence around these types of operations such as presence and condition of equipment and empty seed and fertilizer sacks.
- Examine seed coverage on recently seeded but unmulched areas.
- Examine the effectiveness of mulching, e.g., moisture retention and quick plant growth.
- Assess the diversity of seed or species.
- Note additional soil stabilizing practices such as dozer cleating slopes or tar to tack mulches.
- Measure or estimate the distance between planted trees and shrubs.
- Assure that planting is appropriate and timely for the species; for example, Bermudagrass usually is not sprigged in the fall without a temporary cover crop for controlling erosion.
- Look for "hot spots" or other adversely affected areas that may need lime or fertilizer.

Before concluding the inspection, the inspector should at least on a random basis, and routinely if suspicious of ongoing activity, review an operator's records and receipts that clearly demonstrate soil testing is being conducted before seeding and soil amendments are being purchased and applied. Where topsoil substitutes or overburden mixing has been approved, review of plans versus results in the field should be given special attention.

During various periods of the permit life, the inspector will want to periodically compare revegetation success. These primarily visual reviews will be helpful in discussing problem prevention with the operator and will be used during release application and release periods to determine the appropriateness of bond reductions. Initial inspections should include identification of the reference areas followed by seasonal reviews to familiarize oneself with postmining expectations. Where reference areas are not utilized, the operator will need to be familiar with approved success standards.

For prime farmlands, the release is often based on productivity results and involves the assistance of the USDA Soil Conservation Service (SCS) or other agencies preceding release determinations. Where alternate postmining land uses have been approved, re-examination of the postmining land use section of the PAP during reclamation phases is recommended.

Different or varied considerations may be required where relatively new and long-term mining operations are associated with older prelaw mines on which topsoil was not salvaged. These sites usually belong to one or more of the following types.

Coal processing sites usually are required to have a reclamation plan. While the plan may discuss only final reclamation of the site, the inspector generally is required to observe performance standards for the revegetation of such areas. Areas not actively used should be covered with topsoil where possible after acid/toxic-forming substances are removed and disposed of. Where removal of the toxic material is not possible, adequate layers of nonacid/nontoxic materials suitable as subsoil mediums should be spread before topsoil is distributed. Where topsoil is not available, use of chemical treatments and appropriate species on marginal nontopsoil materials may be adequate for effective cover and plant growth.

In reviewing coal waste disposal sites and waste impoundment structures, the inspector is confronted with 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 agricultural 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.

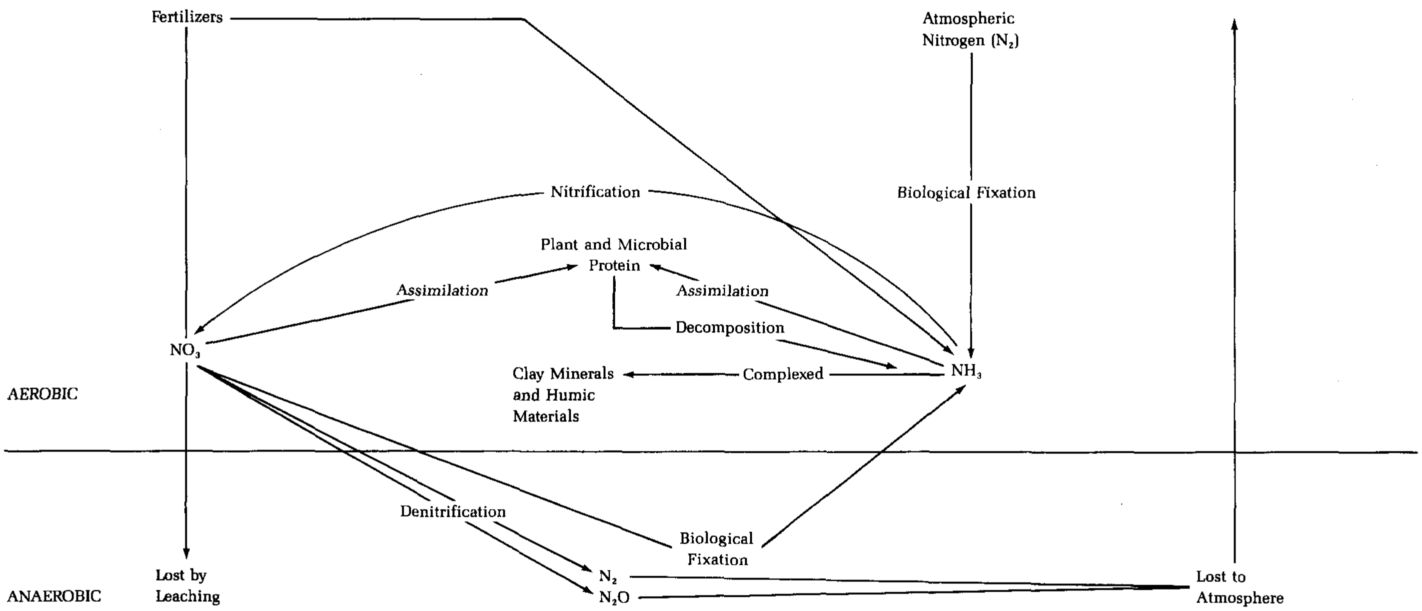


Figure 1. The nitrogen cycle.

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.

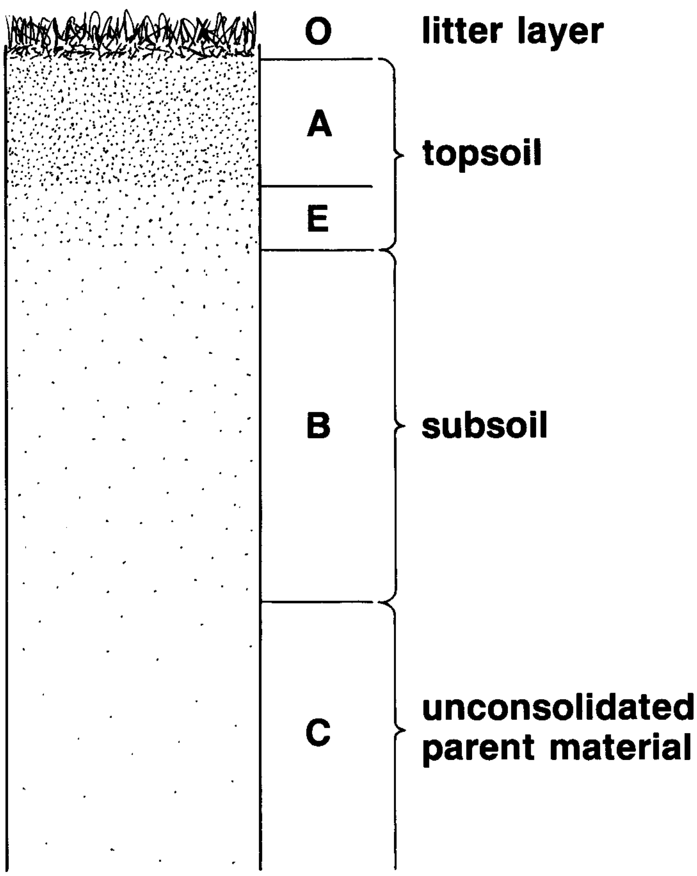


Figure 2. Soil horizons in a mineral soil profile.

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.

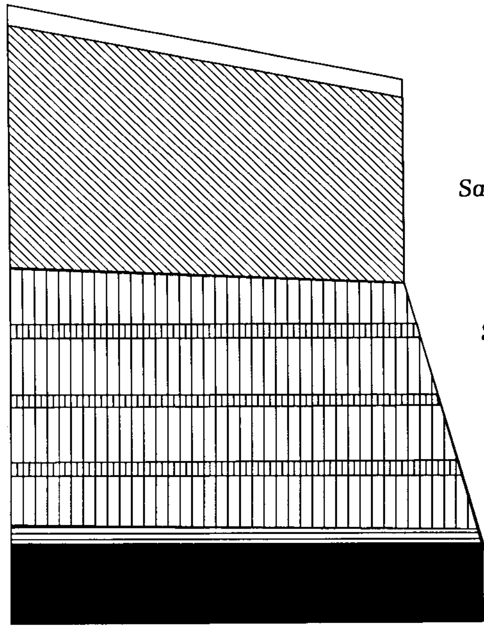


Figure 3. Highwall section of Hazard No. 9 coal seam in eastern Kentucky.

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 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 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, bricklike, 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 l:l 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

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)	

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 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 tension (field capacity) in many soils. Moving soil while it is this wet will cause problems throughout the soil handling, reconstruction, and revegetation processes. Soil moved while wet will compact easily and may be slow to dry. Removing topsoil when the entire soil layer was frozen caused minimal compaction and maintained favorable soil structure and pore space.

Storage and Protection

It is essential that the topsoil, or substitute materials where used, be protected against wind and water erosion, and remain free from contamination by acid or toxic materials.

Storage

A soil survey provides information helpful in selecting sites for stockpiles. Important site considerations are the surface relief, slope length, steepness, aspect, surface and internal drainage conditions, flood hazard, and susceptibility to slippage. Sufficient area should be prepared for each stockpile and hillside sites with springs or seeps should be avoided. Precipitation and runoff should drain away from the stockpile and depressions that entrap water on the stockpile avoided. The approved State regulatory program may contain standards on the steepness and length of each side slope of the stockpiles.

Contaminants

Possible contamination sources include acid-mine drainage, flooding, parking and maintenance of equipment, and dust from haul roads.

Wind and Water Erosion

Stockpiled topsoils and other soil materials may be susceptible to water and wind erosion. Stockpiles that will not be used for reconstruction within 30 days may need to be seeded and mulched. Quick-growing annual or perennial plants can be seeded or planted as soon as weather and seedbed conditions permit after the stockpile is established. In the Western Coal Region, irrigation may be needed to establish cover on stockpiles.

Berms, diversions, or other structures may need to be constructed to retard soil erosion from the stockpile area.

Mulches and Soil Stabilizers

Cereal straw or hay are mulches commonly used to help stabilize soil stockpiles. Other materials being used as mulches include preparations of wood cellulose fiber, wood excelsior, bark, whole-tree chips, and synthetic products. The tacking of straw and hay mulch can be done with various soil-stabilizer products and cellulosic "hydromulches."

Replacement

The replaced minesoil material should be graded to approximate the original soil contour, and to have positive drainage so that any settlement that takes place will not create ponding situations on the reconstructed soils. Treatment such as ripping or scarification may be required to reduce potential slippage of the redistributed materials and to promote root penetration.

Methods

Selection of equipment for replacement and reconstruction of minesoils should be based on the need to provide the least amount of compaction possible. Hauling material to the site in dump trucks (base level dumping) and spreading with small low-ground-pressure dozers generally is acceptable. Soil materials may be returned to the site in parallel windrows with scrapers or trucks and the material then spread between the windrows with road graders or low-ground-pressure dozers. All operations should be designed to minimize traffic on the soil materials. The use of rippers or scarifiers may be required on traffic areas to help alleviate compaction.

Topsoil should be returned to the reconstructed site and placed at a thickness specified in the PAP. Ripping the graded material before replacing the topsoil may help reduce the abruptness of the interface between the two materials and possibly improve root penetration into the lower material. The quality of the root-growth medium also can be improved by adding and incorporating lime where the material has pH values less than 5.5.

All reconstructed soils are subject to wind and water erosion. The extent of this hazard depends on the season of the year, slope length and gradient, soil erodibility of the topsoil material, and the length of time between completed soil reconstruction and the establishment of permanent vegetative cover.

Several erosion control methods can be used to stabilize the soil surface until permanent vegetative cover has been achieved. These include the use of mulches and soil stabilizers, diversions, siltation structures, and windbreaks such as snow fence and temporary vegetative cover. A provision for surface drainage may be needed to handle runoff from the reconstructed soil areas in a manner that minimizes the risk of channel cutting or surface ponding. Fiber netting or other devices may be needed to hold soil and mulch in places where the flow of water is concentrated.

Compaction

Soil replacement activities should be conducted when soils are dry or when moisture content is less than 75 percent of optimum (Standard Proctor Test) to help minimize compaction of the rooting zone. The ultimate goal of soil replacement and reconstruction is to create soil horizons that have moist bulk-density values equivalent to those in a similar layer in the undisturbed soils. In some cases where the natural soils contain layers high in moist bulk-density restrictive to plant growth, it may be possible to create reconstructed soils that have lower bulk-density values. The reconstructed soils could provide a better root-growth medium in this situation.

Moist bulk-density values of soils determined at the permit area before surface mining provide the best benchmark of bulk-density values to use as goals in the reconstruction process. A rule of thumb that could be applied in soil reconstruction is to limit the increase in moist bulk density to 0.2 grams per cubic centimeter over that which existed at a comparable depth before mining.

The moist bulk-density values of the reconstructed soil should allow root extension similar to that in an equivalent layer in the undisturbed soil. This standard is needed to help assure that revegetation can meet the success standard requirement in the PAP.

Compaction during soil reconstruction destroys pore space. This reduces the movement of air and water within the soil and impedes root growth. Errors made in soil handling that result in excessive compaction may be nearly impossible to correct. The best solution to this potential problem is to avoid excessive compaction.

The following guide shows bulk densities that are limiting to plant yields in soils with different particle-size family (textural) classes.

Family class	*Yield-limiting Moist Bulk Density (g/cm^3)*
Sandy	1.80
Coarse-loamy	1.70
Fine-loamy, coarse-silty, fine silty	1.65
Clayey, 35-45% Clay*	1.55
Clayey, 56-75% Clay*	1.30

*For clay contents between 45 and 56 percent, determine density limits by interpolation.

Source: Kansas Standard and Specifications for Land Reconstruction, Currently Mined Land, October, 1984.

Timing

Ideally, soil replacement should be timed to coincide with periods of the year when chances are best for successfully revegetating the reconstructed soils. On some mining operations and in some regions, soil replacement may occur on a nearly continuous basis throughout the freeze-free portions of the year. On these permit areas, there may be special problems in controlling erosion, reducing compaction, and establishing vegetation. In some regions, optimum conditions for replacement are severely limited by weather patterns.

Contemporaneous

Some coal-mining operations move soil materials directly from the area being mined to regraded spoil areas for soil reconstruction. By using this procedure, the operators avoid the costs of stockpiling the topsoil material and other soil layers. During the favorable times of the year, the soil material can be moved without excessive compaction and replaced to form reconstructed soils with rooting zones very similar to those of the unmined soils. But this procedure creates problems in revegetating the reconstructed soils during excessively dry or wet conditions or during cold periods when seedings or plantings will not be successful. Additional protection from wind and water erosion may be required during these unfavorable periods. The use of mulches, soil stabilizers, and temporary vegetative cover may be necessary to protect the soil surface until a favorable period exists for establishing the permanent vegetative cover.

Seasonal

Ideally, soil replacement would be done just before seasons of the year when there is the best chance for new seedings or plantings to become established. In most regions of the country, these ideal planting seasons occur in spring and fall. In some regions, the best season to replace topsoil is mid to late summer when drier soil conditions usually can be anticipated just before the late summer and early fall seeding period. In some regions, spring is the best time to plant but the winter period preceding it is the least suitable time to move and replace soil.

Bond Release Phases

The permittee may file a request for bond release as he or she nears completion of the reclamation work. The permittee is required to publish in a local newspaper (for 4 weeks) his or her intent to seek bond release, and to write to adjoining property owners, local government bodies, planning agencies, water and sewer treatment authorities, or water companies in the locality of the intent to seek bond release. The State regulatory authority will conduct an investigation and find in writing that the operator has satisfactorily accomplished reclamation before any portion of the bond is released.

Phase one

The State regulatory authority may release 60 percent of the bond when the operator completes backfilling, regrading, and drainage control of the bonded area in accordance with the approved PAP.

No part of the bond may be released so long as the lands to which the release is applicable are contributing suspended solids to streamflow or runoff outside of the permit area in excess of requirements set by PL 95-87 section 515 (b)(10).

Phase two

An additional percentage of the bond may be released after vegetation has been established on the regraded mined lands in accordance with the approved PAP.

A portion of the bond is retained by the State regulatory authority to cover possible use of a third party to reestablish vegetation. This portion is retained for the full period of operator responsibility (which may be 10 years or more in western mining regions). This period of time may be needed to meet the success standard required by the law and the approved PAP.

SPECIAL CONSIDERATIONS

This section places emphasis on the special considerations associated with soil removal; stockpiling; replacement; reconstruction; and proof of productivity for prime farmland soils, remined areas, and refuse piles.

Prime Farmland Soils

Special considerations are required for prime farmland soils historically used as cropland. Achieving crop productivity on reconstructed prime farmland soils similar to that on nonmined soils requires careful attention to soil removal, soil transport, soil storage, and soil replacement so that the reconstructed soil will be similar in all aspects to the soil before it was disturbed by mining. The establishment of specifications for soil removal, storage, replacement, and reconstruction of prime farmland soils is the responsibility of the USDA Soil Conservation Service within each state.

Removal

Prime farmland soils are to be removed from areas to be disturbed before drilling, blasting, or mining begins. In general, the minimum depth of soil and soil materials removed and stored for use in reconstructing the prime farmland soils generally should be enough to reconstruct a soil 48 inches deep. Specific depth requirements are established by the Soil Conservation Service and defined in the PAP.

Methods

The operator should remove separately the topsoil, B and C horizons, and/or other soil materials suitable for reconstructing soils with an equal or greater productive capacity than that which existed before mining. The thickness of topsoil to be removed is determined from the soil survey. Topsoil is defined as the A and E horizons taken together. The Ap horizon, consisting mostly of B horizon, also is considered as topsoil. If not used immediately, the topsoil and each horizon or soil material from the prime farmland soils should be stockpiled separately from spoil and other excavated materials.

The equipment selected for soil removal and transport should produce minimum damage to the soil structure and pore space but still allow for effective segregation of the soil layers. Machinery available for soil removal includes bucket-wheel excavators, dozers, scrapers, road graders, and crescent scrapers.

Timing

All vegetative cover that would interfere with salvage of the topsoil and other soil horizons should be removed before soil removal begins from the portion of the permit area to be disturbed. The soil is to be removed before any drilling, blasting, mining, and other surface disturbance.

Soil removal on a nearly continuous basis can be done on some mining operations where the soil materials are placed directly on regraded spoil materials. Other operations will involve stockpiling of topsoil and other soil horizons until they can be placed. Either approach should be timed to take advantage of suitable moisture and possibly temperature conditions to avoid excessive compaction of soil material.

Moisture—Soil removal when the soil is relatively dry, or, more precisely, when moisture content is less than 75 percent of optimum (Standard Proctor Test), will help maintain soil structure, reduce compaction, and reduce loss of pore space. Moving soil materials while wet will cause problems throughout the soil handling, soil reconstruction, and revegetation processes.

Temperature—Moving soil when it is frozen caused a minimal amount of compaction and maintained favorable soil structure and pore space. It is desirable that the entire layer of soil being lifted and moved is frozen. The benefit of moving frozen soil would be negated if only a part of the layer was frozen, especially if the soil were wetter than desired.

Protection

The prime farmland soil materials should be protected during the soil removal and stockpiling stages to minimize compaction and to prevent or retard wind and water erosion and contamination. Mixing with rock, vegetative debris, and other nonsoil materials is the most likely form of contamination to occur during soil removal.

Storage

Selection of suitable sites for stockpiles is important for maintaining the quality of the stored soils. Stockpiles of prime farmland soil material should be placed within the permit area where they will not be disturbed or subjected to excessive wind or water erosion nor contaminated by acid or toxic overburden materials, acid drainage, flooding, and fluids and lubricants drained from equipment. Stockpiles of topsoil and B and C horizons from prime farmland soils should be segregated from stockpiles of other soil and overburden materials.

The soil survey provides information that can assist in site selection for stockpiles. Important features to be considered are the surface relief, slope length, slope gradient, slope direction (aspect), surface and internal drainage conditions, flood hazard, and susceptibility to slippage.

Sufficient area should be prepared for each stockpile to allow easy access and to provide space for building temporary structures, such as diversion terraces, needed to protect the stockpiles from erosion and contamination. The Approved Regulatory Program may contain standards on the steepness and length of each side slope of the stockpiles. Each stockpile should have positive drainage to assure that precipitation and surface flow drains away from the stockpile.

Wind and Water Erosion

Erosion by wind and water may be a hazard during the removal and stockpiling of prime farmland soil materials. Protecting these materials from erosion is necessary during all phases of handling. Berms, diversions, or other temporary structures may be needed to prevent surface runoff from entering and eroding soil materials from areas where the soils are being removed and from stockpiles.

The use of mulches and soil stabilizers also may be needed along with the use of temporary vegetative cover.

Water erosion is the main concern in the Appalachian and Interior Coal Regions. Sheet and rill forms of water erosion can be a potential hazard on areas where the soil materials are being removed and on stockpiles, particularly during times of the year when substantial rain can be expected for extended periods. Stockpiles of soil that will not be spread within 30 days may need to be mulched or seeded and mulched. Where needed, quick growing annual or perennial cover crops should be seeded or planted as soon as weather and seedbed conditions allow after the stockpile is established.

The Western Coal Region has potential for both wind and water erosion. Areas where prime farmland soil is being removed and the stockpiles of these soil materials are vulnerable to both types of erosion because of the absence of protective plant cover. Mulches and soil stabilizers may be needed to control wind erosion even on stockpiles that will be used in a few days. Stockpiles that will not be used within 30 days may need to be seeded and mulched. Irrigation may be required to obtain vegetative cover quickly.

Reconstruction

The placement and reconstruction of prime farmland soil material should be such that the reconstructed soils will have the capacity of achieving yields equal to or higher than those on nonmined prime farmland in the surrounding area. Specifications for reconstruction of prime farmland soil are established by the SCS within each state and include, as a minimum, physical and chemical characteristics such as soil horizon depths, densities, and pH.

Land Shaping and Drainage

The land surface must be shaped to obtain adequate surface drainage before the topsoil and root zone materials are replaced and graded. Broad, flat areas should be avoided because any differential settling of materials will create ponding. Gentle slopes of about 2 percent are preferred.

Surface drainage should be designed on the assumption that the final reconstructed soil will be slowly permeable and runoff will be relatively high. Drainageways with sufficient capacity to handle this higher runoff may be required. Where surface mining of adjacent unmined land is anticipated, it may be advisable to plan for the handling of runoff from that land, particularly where drainage from both areas may need to be handled in common drainageways.

Depth of Soil Reconstruction

In general, the depth of reconstructed prime farmland soil should be 48 inches. Specifications for greater or lesser depths will be provided by the SCS based on the soil survey and established crop yields.

A depth less than 48 inches for reconstructed soil may be permitted where a subsurface horizon that inhibits or prevents root penetration is found in the natural soil at a depth less than 48 inches. Soil horizons are considered as inhibiting to root penetration where their physical or chemical properties or water supplying capacities restrict or prevent penetration by roots of plants common to the area, and these properties or capacities have little or no other beneficial effect on productive capacity of the soil.

Depths greater than 48 inches may be required for some prime farmland soils to assure restoration of productivity. This may occur where the rooting depth of plants common to the area generally is greater than 48 inches.

Topsoil

The operator should replace the topsoil or other suitable soil materials that have been approved by the regulatory authority as being capable of creating a soil with equal or greater productive capacity than that which existed before mining. This surface soil layer should equal or exceed the thickness of the original surface soil layer, as determined by the soil survey.

- Density—The density of the replaced and reconstructed topsoil should be within the range for the A and E horizons cited in the soil survey and given in the permit application (to qualify for phase one bond release). Where a scraper has been used to redistribute the topsoil and no ripping or other practice is used to break the compaction caused by the scraper, the soil will be considered as not meeting the regrading standard because of overcompaction. Acceptable methods of placement of topsoil material include the use of trucks (base level dumping) with dozer spreading. One method that leaves the soil in a favorable physical condition and minimizes compaction is the final placement of soil by conveyor belt followed by dozer spreading.
- Texture—The texture of the replaced topsoil should be of the same soil textural class as that of the prime farmland soil before mining, unless an approved substitute topsoil is used. Where more than one prime farmland soil occurs on a permit area, the texture of the reconstructed topsoil may be that which would result from a mixture of the topsoil from each of these prime farmland soils.
- Thickness—The thickness of the reconstructed topsoil should be the same as the average thickness of the prime farmland soil in the permit area before mining. Where more than one prime farmland soil occurs on a permit area, the thickness of the topsoil should be representative of each of the prime farmland soils being reconstructed.
- pH—The pH should be the same as that of the prime farmland soils in the permit area before mining. Modifications due to mixing of nontopsoil materials should result in raising the pH to no more than 8.0 or lowering it to no less than 5.0.
- Other Properties—Available water capacity, cation exchange capacity, and porosity of reconstructed topsoil should be similar enough to the prime farmland soil before mining to allow restoration of productivity.

Subsoil

The B horizon, C horizon, or other suitable material that has been removed should be replaced to the thickness that meets the minimum depth requirements for restoring soil productivity.

- Density—Subsoil materials should be replaced with proper compaction. Proper compaction of regraded subsoil generally means that no layer within the subsoil has a bulk density (1) greater than that of the most dense layer of the B horizon of the prime farmland soil before mining or (2) greater than the most dense value for the horizon cited in the SCA SOI-5 form for the prime farmland soil.

There is no optimum density applicable to all prime farmland soils because of the differences in the makeup of soils. Soil-density specifications are a part of the soil reconstruction specifications developed by SCS in each state. SCS will determine proper compaction for each prime farmland soil to be reconstructed.

Replacing the prime farmland soil materials when they are relatively dry or, more specifically, when moisture content is less than 75 percent of optimum (Standard Proctor Test), will help minimize compaction. The optimum moisture content for plant growth is about that of ⅓ bar tension (field capacity) in most soils.

Where scrapers are used to place and regrade the subsoil, some form of ripping or chiseling generally is required to correct excessive compaction. It is important to monitor and correct the density of lower layers while they can be reached with the rippers or chisels. Placing soil amendments such as lime on the subsoil layer before ripping or chiseling will help correct strongly acid soil conditions and may help achieve restoration of productivity.

- Texture—The texture of the reconstructed subsoil should be that which would result from the mixing of the subhorizons of the B horizon, or from a mixture of these subhorizons and approved portions of the C horizon. Where more than one prime farmland soil occurs on a permit area, the texture of the reconstructed subsoil may be that which would result from a mixture of subsoil materials from each of the prime farmland soils. No material should be mixed into reconstructed subsoil that is toxic or otherwise harmful to plant growth.
- Thickness—Subsoil material should be returned uniformly at a thickness not less than the combined average thickness of the unmined B and C horizons above 48 inches or to a restrictive layer if less than 48 inches.
- pH—The pH should be the same as that which would result from the mixing of the subhorizons of the B horizons or from these subhorizons mixed with approved portions of the C horizons of the prime farmland soil or soils. If the resulting pH is less than 5.0, the operator can raise the pH of the subsoil by adding lime.

Timing

The reconstructed prime farmland soils should be seeded or planted when most of the crops, grasses, trees, and shrubs are customarily seeded or planted in the area. Replacement and reconstruction of the prime farmland soils would ideally be timed to take advantage of the best planting and seeding seasons of the year. However, this may not coincide with the best time to move, handle, place, and grade soils. In some regions, spring is the best time to seed and plant, but the winter months preceding usually are not a desirable time for handling soil because of high precipitation and low evaporation. Thus, soils are subject to severe erosion and remain wet and in some areas do not freeze deep enough to move layers of soil that are entirely frozen. The best alternative in these regions is to reconstruct soils during the dryer summer months and seed and plant in the fall. Handling of soil in the summer may be a high risk because of excessive wind erosion in some regions or storms with high-intensity precipitation in other regions. Reconstruction during any season of the year may be accompanied by erosion hazards, overcompaction, and difficulty in establishing vegetative cover. Thus, proper timing for reconstructive soils depends partly on choosing the most appropriate season in a given region and partly on the good fortune of receiving favorable weather regardless of the season of the year.

Bond Release

Permit areas containing prime farmland have special requirements for two phases of bond release.

Phase One

The State regulatory authority may release 60 percent of the bond when the operator completes backfilling, regrading, and drainage control on the bonded area in accordance with the approved reclamation plan. Bonded areas containing prime farmland soils must meet specific requirements for phase-one bond release. The requirement that will be the most troublesome for the operator is to replace and regrade the soil horizons or other root-zone materials within limits of proper compaction and uniform depths.

Phase Two

An additional portion of the bond may be released after soil productivity for the prime farmlands has been returned to levels of yield equivalent to nonmined land of the same soil type in the surrounding area under equivalent management practices.

Soil productivity should be measured within 10 years after soil replacement is completed. Soil productivity is measured on a representative sample or on all of the mined and reclaimed prime farmland area using the approved reference crop. The measurement period generally is for a minimum of 3 years before release of the operator's performance bond. The level of management applied during the measurement period should be the same as that used on nonmined prime farmland in the surrounding area. Restoration of soil productivity is considered complete when the average yield during the measurement period equals or exceeds the average yield of the reference crop grown during the same period on comparable nonmined prime farmland soils in the surrounding area under equivalent management practices.

The approved regulatory program provides requirements for reconstructed prime farmlands specific to the State concerned.

Remined Areas

Revegetation of remined areas is a special consideration because of the previous disturbance. Topsoil may or may not be present on the previously mined area depending on the age of the minesoil and the amount and type of vegetation. If the site has dense and productive vegetational cover, a relatively thin layer at the surface of the minesoil will most likely be the best available plant-growth medium and should be reserved for that purpose. If vegetation is sparse or absent, soil samples should be collected on a grid pattern and analyzed to determine the best available plant-growth media. Careful labeling and mapping are necessary to identify the location from which each sample was collected. Analysis of the minesoils will show amendment requirements to achieve proper pH and nutrient levels.

Hot spots, i.e., areas of minesoil containing materials toxic to plant life, should be identified before mining. These materials should then be segregated when mining starts and buried as part of the reclamation procedure.

After mining, revegetation can follow standard procedures for applying amendments, selecting species, and seeding, planting, and mulching to achieve the desired land-use objective.

Refuse Piles

Refuse piles resulting from coal preparation plants or deep-mine operations present a unique revegetation problem. Usually, topsoil or substitute materials are not available. The dark color of the refuse can absorb enough solar energy to raise temperatures to levels that are lethal to plants. The materials are often highly acidic and deficient in plant nutrients.

A complete analysis of the refuse material is necessary before a revegetation prescription can be developed. Topsoil or substitute material available for covering the refuse should be analyzed at the same time. The analyses will identify lime and fertilizer requirements.

Where topsoil or substitute materials are available and the refuse is very acid, it may be necessary to neutralize the refuse before applying the surface layer of plant-growth media. The surface layer should then be limed and fertilized according to the results of the soil tests. Seeding, planting, and mulching can then be performed following accepted procedures.

Where there is no topsoil or substitute material available, revegetation of the refuse is more difficult. Lime and fertilizer requirements, as determined by the soil tests, should first be satisfied. Seeding and planting should be followed by a very heavy application of mulch. Coarse mulches such as bark, wood chips, or straw provide more protection from solar insolation than the cellulose fiber mulches. Enough mulch must be applied to completely cover the refuse and provide some shading of the newly germinated plants.

Incorporating organic materials, such as sewage sludge, composted municipal wastes, livestock and poultry manures, shredded bark, composted leaves, papermill sludge, mushroom compost, and mixtures of some of these materials, has greatly enhanced revegetation of coal refuse piles as well as abandoned acid-mine spoils. In some cases, additions of lime and fertilizer were not needed where moderate to high rates of these organic materials were applied.

Fall seeding with a mixture containing a temporary cover species, such as winter wheat or rye, and permanent species has proved successful in test plantings. The cool fall weather promotes the development of the cover species which provide a living mulch to protect the other species as they germinate and start growth in the spring. Tree and shrub seed can be included in the fall seeding mixture or seedlings can be planted in the spring.

Due to the severity of this type of site, germination and plant establishment may be spotty. The land manager should be prepared to spot treat open areas to obtain an overall cover.

VEGETATION ESTABLISHMENT AND CULTURAL PRACTICES

The use of appropriate cultural practices and amendments and adherence to proper seeding and planting techniques will greatly increase chances for success in establishing vegetation. In fact, success in revegetating minesoils may be more dependent on the proper use and application of these practices and amendments than on the selection of plant species.

Soil Amendments

Successful establishment of vegetation on minesoils usually requires the applications of one or more soil amendments. Amendments are materials applied and incorporated into soils to cause immediate changes in soil physical and chemical properties. Amendments should not be confused with mulches, which are used to alter surface characteristics and environment. Field and laboratory soil chemical and physical tests are needed to determine amendment requirements.

Fertility Management

Several criteria may need to be considered in determining the kind and amount of fertilizer to use: (1) nutrient availability in the spoil or soil, (2) nutrient requirements of plant species to be established, (3) effect of fertilizers on minesoil properties, (4) cost, (5) requirements for refertilization, and (6) availability of water.

Fertilizer requirements and recommendations vary with different land uses and management situations. For agricultural uses, fertilizer application is based mainly on soil tests and follows the recommendations of local agricultural specialists for the crop being planted. Criteria for agricultural use may include split applications for crop establishment and periodic applications thereafter for crop maintenance.

For forestry and wildlife habitat land uses, fertilizer is applied primarily for the initial establishment of a vegetative cover for erosion control. Generally, this requires a lower fertilizer rate than for agricultural uses, and maintenance applications usually will not be required. Ideally, without maintenance applications, density of the initial cover will gradually diminish or composition will change and thereby improve the chances for planted and naturally seeded woody species to develop.

Soil testing for needed fertilizer is less important for forestry or wildlife-habitat land uses, or where herbaceous cover is established primarily for erosion control or esthetic purposes, than it is for agricultural uses. Without a soil test or with no previous knowledge of fertility requirement, a minimum rate of fertilizer recommended for establishing herbaceous seedings is about 60 pounds of nitrogen (N) and 100 pounds of phosphate (P_2O_5) per acre. On minesoils that have not been topsoiled, application of potassium fertilizer may not be needed; but where it is used, a rate of about 30 pounds per acre of potash (K_2O) is suggested. Native soils in some regions are low in potassium; thus, a higher rate of potash may be needed on mined areas that have been topsoiled.

The benefits of fertilizing woody species are not as predictable or economically attractive as fertilizing herbaceous species. Woody species fertilized with nitrogen or phosphorus, or both, usually show a positive response in height growth, vigor, and color. In some plantings, increased mortality of newly planted tree seedlings results from the use of fertilizer—both from broadcast application and from placing fertilizer pellets in the planting hole. In other plantings, tree survival is not affected by fertilizer placed either in the planting hole or near it.

The establishment and early growth of direct-seeded trees and shrubs usually are improved by fertilization with nitrogen and phosphorus. However, where trees and herbaceous species are seeded together, the rapid, vigorous growth of the herbaceous vegetation in response to fertilizer may suppress or prevent the establishment of seeded trees.

Requirements for maintenance fertilization of established vegetation are determined primarily by land-use objectives. For agricultural uses, fertilization programs similar to those used in the management of any agricultural land may be required for continued crop productivity. Because the fertility of minesoils can vary in different areas, the requirements for maintenance fertilization in agricultural uses must be determined mainly from experience and periodic soil testing.

For reforestation and wildlife habitat, little if any refertilization should be needed once the required vegetative cover and number of woody species are established. Thereafter, natural processes are mainly responsible for the continued maintenance and development of plant communities. For example, herbaceous and woody legumes help provide nitrogen by way of the associated nitrogen-fixing bacteria. Populations of other microorganisms that aid plant nutrition, especially mycorrhizal fungi that help plants obtain phosphorus from the soil, also will increase as vegetation becomes established. Application of fertilizer, especially at high rates, can impede the development and function of these beneficial organisms. Thus, refertilization is not advised where it does little to benefit or may even interfere with the natural development of plant communities.

Important Nutrients

Sixteen elements are considered as essential nutrients for plant growth. Those nutrients most likely to be deficient and of most concern in fertilizing soils are nitrogen, phosphorus, and potassium. Other nutrients may be deficient in specific soils or localized areas.

• Nitrogen—Most minesoils are deficient in nitrogen (N). Soil tests that estimate N status from organic matter can grossly overestimate N content when the minesoil contains coal fines or dark shales. Organic matter in such determinations also may be biologically inert. Some tertiary and cretaceous shales may contain appreciable N, however. Test plots with different N applications are advisable if there is doubt about N requirements. For these tests, it should be remembered that N usually is far more limiting to plant productivity than it is to seed germination.

Where N is low in minesoils, 40 to 60 pounds/acre may need to be added. Where mulches, such as straw, are used, 50 to 60 pounds or more/acre may be called for. (See the mulch section for mulch N requirements.)

Nitrogen is commonly available in ammonium nitrate, ammonium sulfate, urea, ammonium phosphates, manure, and sludge. Nitrogen-fixing plants frequently are used on surface mined lands, but most of the nitrogen fixed is not available to other plants during the first growing season. Dark topsoils also may contain a significant amount of N.

The nitrate form of N is particularly mobile because the ion is not absorbed on clay particles. Thus, it is particularly susceptible to loss by leaching. As negatively charged nitrate ions leave the soil body, an equivalant amount of positively charged calcium, magnesium, potassium, and other ions also will leave so that the electroneutrality of the soil mass is preserved. Soil organic matter helps hold nitrate and reduce leaching losses.

Nitrogen fertilizers can be applied at the same time as seed in the spring, but the fertilizer should not be in contact with the seed. Where late-fall seeding is used, the application of N, or most of it, is better left until spring to avoid leaching losses. The effect of N fertilization often is temporary. Split application in the first growing season and refertilization later may be required. If annual weeds are anticipated to be a problem, it may be desirable to delay N-fertilization until the desirable vegetation has germinated and become established, possibly even as late as the start of the second growing season. Application of N on established vegetation can cause a "greening up" effect that looks good, but if this precedes a dry spell, the additional shoot biomass requirements for water may outstrip the roots' ability to provide it and lead to a die-off of vegetative cover.

Nitrogen deficiency in plants generally is seen as a yellowing of older leaves, "firing" or drying of leaves starting at the bottom of the plant, and slow or dwarfed growth. This phenomenon can be used as an indicator of the need for maintenance fertilization with N. Soil tests may be needed to confirm this because other factors may be involved.

• Phosphorus—Most minesoils also are deficient in phosphorus (P), but there are exceptions. Soil tests that show plant-available P are the most meaningful for determining need for P fertilizer. Phosphorus sufficiency is particularly critical to the establishment of seedlings. P-deficient plants may not be able to grow enough of a root system to extract sufficient water so that drought appears to be the cause of vegetation failure. P-deficiency symptoms include purplish leaves, stems, and branches, low seed yield, slow growth, and delayed maturity.

Phosphorus is applied as phosphate, P_2O_5. Applications of 100 pounds/acre are common on coarse soils; 200 pounds/acre are commonly used on clays. Applied P fertilizer should be worked a few inches deep into the soil.

Phosphorus sources include super phosphates (42 to 53 percent P_2O_5), ammonium phosphate, diammonium phosphate, sewage sludge, and manure. The latter two sources usually can supply sufficient P if they are applied in sufficient quantity to meet soil N requirements. Soluble P sources (ammonium phosphates and super phosphates) should be used on neutral and basic minesoils.

Phosphorus fertilization is long lasting and seldom needs repetition. Much of the applied P will be converted into organic and less available forms that will be released again as vegetation requires it.

• Potassium—Potassium (K) usually is not deficient on minesoils, particularly when clays are present in the spoils. Soil tests should be used to confirm this. Most of the standard soil tests for K give meaningful results for determining requirements for K fertilizer.

• Calcium and Magnesium—Calcium (Ca) and Magnesium (Mg) are sometimes initially deficient on acid spoils. Liming corrects Ca deficiencies and use of dolomitic limestone also corrects Mg deficiency. Mg toxicity may develop in minesoils where the Ca:Mg ratio is below 1:1, based on soil tests that measure soil solution on "available" amounts. Use of dolomitic limestone to neutralize some highly pyritic acid spoils may cause problems in revegetation due to the formation of high levels of Mg salts.

Grass tetany in animals is caused by low Mg concentration in blood which, in turn, is related to low Mg concentrations in forage. Mg fertilization is desirable where soil tests show that "available" Mg is less than 50 ppm or 100 pounds/acre in soils planted in forage crops.

Ca and Mg are not very mobile in soils. When lime is applied to correct Ca and Mg deficiencies, it should be worked into the soil to a depth of at least 6 inches.

Fertilizer Terminology

Fertilizer recommendations often are confusing to those unfamiliar with fertilizer terms. Most commercial fertilizer materials include three major nutrients: nitrogen, phosphorus, and potassium. Fertilizer recommendations usually are made on the elemental basis for nitrogen (N) and on the oxide basis for phosphorus and potassium, i.e., phosphate (P_2O_5) and potash (K_2O). The "analysis" of a fertilizer material is the listing of the percent of each nutrient, always in the order: N-P_2O_5-K_2O. Fertilizer labeled as 8-24-16 contains 8 percent by weight of N, 24 percent of P_2O_5, and 16 percent of K_2O. Fertilizer labeled as 10-10-10 contains 10 percent by weight of each nutrient. This applies to both dry and liquid fertilizers. Thus, if a gallon of liquid fertilizer is labeled as 10-20-10 and weighs 10 pounds, it contains 1 pound of N, 2 pounds of P_2O_5, and 1 pound of K_2O.

Fertilizers that contain only one of the nutrients are called "straight" fertilizers. For example, 34-0-0 is ammonium nitrate and contains only nitrogen. Fertilizer labeled 0-46-0 is concentrated super-phosphate and contains only P_2O_5. Muriate of potash, labeled 0-0-60, contains only K_2O. "Mixed" fertilizers contain two or all three of the nutrients; for example, 18-46-0, 0-20-20, or 8-16-8.

Fertilizers can be obtained in various formulas, but there are advantages to using or mixing "high-analysis" fertilizers—those that contain the greatest amount of the nutrient or nutrients. For example, a mix of 220 pounds of 18-46-0 fertilizer, plus 60 pounds of 34-0-0 fertilizer will provide 60 pounds of N and 100 pounds of P_2O_5, a suggested minimum per-acre rate for establishing ground cover. With this mixture, 280 pounds per acre of bulk fertilizer are needed. But if a fertilizer such as 10-10-10 were used, 1,000 pounds of bulk fertilizer would be required to meet the 100 pounds per acre P_2O_5 requirement. This amount of fertilizer also would supply 100 pounds of N and 100 pounds of K_2O. The amount of N would be somewhat in excess of that required or needed; the K_2O may not be needed at all or be in excess of need. The advantages, then, of combining and using high-analysis fertilizers such as a 18-46-0 and 34-0-0 instead of using low-analysis fertilizers such as 10-10-10 are:

(1) Less bulk material is involved, so transportation, handling, and storage costs are reduced. For application by aircraft it is especially important to apply the most nutrients in the least amount of bulk material. (In the previous example, 1,000 pounds of 10-10-10 had to be used compared to 280 pounds of the high-analysis mix.)

(2) Cost is less because the cost of fertilizer is based on the cost per pound of nutrients. Applying unneeded nutrients increases the cost of applying fertilizer.

(3) High-analysis fertilizers usually have a lower salt concentration per unit of available nutrients; this reduces the chances of salt damage to seed, especially when seed and fertilizer are mixed in a hydroseeder.

Fertilizer Application

Fertilizer usually should be applied at about the same time that seeding is done, preferably when the seedbed is being prepared. However, when seeding is done in the dormant season, fertilizer, except for phosphorus, should not be applied until about the time that the seeds begin to germinate in the spring. Incorporating fertilizer, particularly phosphorus, into the minesoil generally is recommended, especially on fine-textured soils. Tillage for mixing fertilizer into minesoils may not be necessary where the fertilizer is applied on a roughened, freshly tilled seedbed.

Fertilizer can be applied dry with cyclone or broadcast-type spreaders, pull-type flow spreaders, regular lime-spreading trucks or those with the Estes Aerospread™ attachment, and with aircraft. It can be spread by hand on small areas.

Fertilizer also can be spread with a hydroseeder, either by itself or mixed with the seed. Where mixed with seed, the slurry should be spread as soon as possible to prevent damage to the seed by the salt solution formed from the mixture of water and fertilizer. This salt solution also can kill the bacteria in a legume inoculant, as discussed in a later section.

Amelioration of Acidity

Minesoil acidity causes more problems for vegetation than a mere acid environment for plant roots. The concentration of many ions in soil solution is pH dependent. Low pH releases toxic amounts of iron, aluminum, and manganese into soil solution. Heavy metals such as selenium, chromium, nickel, and cadmium also are more available under acid conditions. Phosphorus availability decreases under acid conditions.

Liming Materials

The most common method of ameliorating minesoil acidity is a lime application. The ability of a liming material to neutralize acid is evaluated by comparing it with the neutralizing ability of pure calcium carbonate. This relative neutralizing ability or value is expressed in percent. For example, the neutralizing value of hydrated lime is 135 percent, but some agricultural limestone may be as low as 80 percent. This and other chemical information should be available for liming materials sold commercially for agricultural uses.

Agricultural lime (ground limestone) is the material most used for amending acid soils. Limestone from different quarries and different parts of the country may vary in its neutralizing value or "calcium carbonate equivalent" or CCE. Thus, adjustments to increase liming rates should be made where lime with a low neutralizing value is used. For example, if a liming recommendation calls for 2,000 pounds per acre of CCE and lime has a neutralizing value of 85 percent, then (2,000/85) x 100 = 2,350 pounds, the actual amount of agricultural lime required.

It is important that agricultural lime be ground to meet particle-size or fineness standards recommended by the U.S. Department of Agriculture. Most dealers licensed to sell agricultural lime meet these or similar standards required by State regulation. Finely ground limestone dissolves faster than coarsely ground and reacts faster with the acid in the soil. Adjustments should be made to increase liming rates where lime with a coarse grind is used. In fact, using additional lime, with a mix of particle sizes, even as much as double the recommended rate, can benefit the establishment and maintenance of vegetation on spoils high in sulfides, because a greater quantity of the finely ground limestone is available to quickly react with the active acidity. The slower dissolving coarse particles may provide a reserve for neutralizing acid produced in the future from oxidizing sulfides; but in some situations, the coarse particles of limestone become coated with iron oxides and are rendered ineffective for neutralizing acid.

Limestones from different geologic formations also may vary in the content of magnesium carbonate. Those containing little or no magnesium are called calcitic; those with relatively high amounts are called dolomitic. The neutralizing value of dolomitic limestone usually is higher than calcitic limestone. Either type of limestone can be used on most minesoils, though dolomitic materials are most beneficial for soils low or deficient in magnesium. By contrast, toxicity to plants is known to occur where acid minesoils already relatively high in Mg were treated with high rates of dolomite.

Hydrated lime (calcium hydroxide) also is useful for amending acid soils, but this material is more expensive than agricultural lime and more difficult to apply with conventional spreading equipment. However, the use of hydrated lime may be desirable where it is necessary to treat small, hard-to-reach areas. The neutralizing value of hydrated lime is 135 percent; only 1,480 pounds of it are required to equal the neutralizing ability of 2,000 pounds of pure calcium carbonate. Because all of the hydrated lime is immediately effective for neutralizing acid, it does not have the lasting effect of agricultural lime that contains both fine and coarse particles.

Burnt lime (calcium oxide) is not commonly used but may be available in some areas. It is very soluble in water. This allows an immediate effect on minesoil pH, but it is not long lasting. Immediately after application, soil pH may rise temporarily to 8.5 to 9.0. The pH should be allowed to stabilize in such cases before fertilizer is applied.

Some industrial waste products such as calcium silicate slag and alkaline fly and bottom ashes have been used as liming materials, but they usually are less effective than agricultural and hydrated limes and sometimes cause other toxicity problems. For example, fly ash from some sources contains levels of boron that are toxic to vegetation grown on sites treated with large amounts of the fly ash. Lime residue from sugar beet processing also can be used.

Rock phosphate provides a long-term, slowly available source of phosphorus for plant growth and helps neutralize acidity. However, it has less neutralizing ability than agricultural lime at similar rates. The feasibility of using rock phosphate must be based primarily on the cost of obtaining and applying it compared to the cost of using lime and high-analysis phosphorus fertilizer.

Liming Rates

Standards for lime requirements usually are expressed in terms of liming the soil to a prescribed pH level. For agricultural uses, a pH of about 6.5 generally is recommended. For forestry and wildlife-habitat land uses in the eastern United States, a pH of at least 5.5 usually is prescribed. One reason for this is that plant species used for reforestation and wildlife habitat generally are better adapted to acid soil than species used primarily for agricultural purposes.

Ideally, soil tests should be used to determine liming rates for acid minesoils and refuse materials. However, where the appropriate soil tests cannot be obtained, general guides, such as the following based on soil-water pH values, usually produce acceptable results for liming minesoils that are not extremely acid (above pH 4.0).

pH (soil-water suspension)	*Rate (tons/acre CCE)*
6.1 and higher	None
6.0 to 5.5	1 to 2
5.4 to 4.6	3 to 4
4.5 to 4.0	5 to 6

For determining lime requirements on minesoils and refuse materials that are extremely acid (below pH 4.0) and those known or suspected to be high in sulfides, soil testing is especially important because lime requirements can vary greatly in these materials, even among those with the same pH. On materials where standard soil tests, such as the SMP Buffer pH, indicate liming rates of 20 to 25 tons per acre or more, a total sulfide analysis (potential acidity test) also is recommended, and lime application should be increased accordingly. If the total sulfide analysis cannot be obtained, lime should be applied at about 1.5 times the rate indicated in the standard soil test. An alternate strategy is to apply and incorporate at least 25 tons of lime per acre and retest with the standard soil test 4 to 6 months later. Additional lime as indicated by the test should be applied and incorporated. A temporary cover crop for reducing erosion should be sown during the periods between tests.

Liming rates indicated by soil tests are the amounts needed to amend soils to a depth of about 6 inches (also referred to as the plow layer). These rates may be expressed as some unit of weight per unit of area, such as tons/acre, or as some unit of weight per weight of a unit area, such as tons of lime/1,000 tons of soil. One thousand tons is considered as the weight of an acre of average soil 6 inches deep. Accordingly, lime should be incorporated about 6 inches deep. But in extremely acid material, this means that the growth of plant roots is limited to the depth to which lime has been incorporated. Thus, to increase the potential rooting depth of vegetation on extremely acid materials, lime should be incorporated 10 to 12 inches deep or deeper if possible. However, where there is deeper incorporation of lime, the quantity of lime applied must be increased accordingly; where incorporated 12 inches deep, for example, the rate of lime indicated by soil tests should be doubled.

Where topsoils will be spread over acid minesoils, it is desirable to apply lime on the minesoil and incorporate it before covering with topsoil. This may provide a better rooting environment at intermediate depths.

The need for maintenance application of lime, as with initial application, should be determined by land-use requirements. Topdressing with lime to maintain a pH of about 6.5 is recommended for agricultural production. Maintenance applications for forestry and wildlife habitat may not be required unless periodic soil tests indicate a continual decline in pH below 5.5, or a visual inspection indicates that lime is needed to maintain existing vegetation.

Application

Agricultural lime can be spread with conventional lime-spreading trucks on areas that are accessible to vehicles. Application on steep slopes and on accessible areas can be made with the Estes Aerospreader—a blower-impactor device that is mounted on a lime-spreading truck. Hydrated lime can be applied on relatively smooth and level land with a pull-type, gravity-flow spreader, and on steep slopes with a hydroseeder.

Lime should be incorporated into the soil, preferably to a depth of about 6 inches, before seeding or planting vegetation. A heavy-duty disc or chisel plow is useful for incorporating lime on most minesoils; but on steep slopes, incorporating lime by any means is a major difficulty. Some form of tillage up and down slope may be possible with a dozer, but the furrows would collect runoff water and quickly initiate gully erosion. Lime applied on the surface and not incorporated will be of limited benefit in establishing vegetation, but it is of some value for topdressing areas that already are vegetated.

Lime can be applied at any time that the spreading equipment has access to a site. Ideally, agricultural lime should be applied and incorporated several weeks or even several months before seeding. This probably can be accomplished on most older mined sites and refuse piles. However, newly mined areas should be seeded as soon as possible after grading is completed. Thus, lime usually will have to be applied immediately after grading and given little or no reaction time in the soil before seeding. One way to compensate for the reduced reaction time is to apply from 10 to 50 percent additional lime. Extremely acid materials that initially require large amounts of lime also will require the greater percentage of additional lime. Large quantities of agricultural lime properly incorporated usually will not inhibit the establishment of seeded vegetation. In eastern Kentucky, calcitic limestone was applied on extremely acidic spoils high in sulfides at 8 times the rate indicated by the soil test without adversely affecting the seeded vegetation.

In addition to correcting low pH, lime also:

- Adds calcium to the soil.
- Speeds decomposition of organic matter and releases N.
- Increases the efficiency of fertilizer.
- Increases nutrient availability.
- Decreases aluminum and iron toxicity.
- Improves the physical condition of the soil.

Amelioration of Toxic Elements

Some minesoils have high amounts of heavy metals or other elements present in toxic concentrations. Some of the revegetation problem may possibly be solved by the use of plant materials that tolerte these elements. Amending minesoils to modify their chemistry also helps. As discussed under liming, raising soil pH can decrease the soil solution concentrations of toxic elements. On alkaline spoils, lowering pH can help control availabilities of elements, such as chromium and molybdenum, which are least "available" in the pH range of 5 to 7. Soil chemistry modification can be a complex and sometimes costly process. Local SCS and State extension soil scientists should be consulted for help with specific problems. Where there are plans to use reclaimed lands for forage production, potential toxicity of boron, selenium, and molybdenum must be considered.

Sodic Soils

Minesoils high in sodium may require the use of sodium-tolerant plant species. In more extreme cases, sodium in the soils causes "dispersion" of clay particles. This leads to loss of structure and poor water infiltration and percolation.

Sodium frequently can be leached from sodic soils with irrigation water. Adding topsoil and organic matter helps improve soil aggregation and speeds leaching of sodium. Discing and subsoiling to improve structure and drainage may be beneficial, but deep tillage should be avoided in areas with a high water table or where tillage might encourage water to rise to the surface and carry sodium into the rooting zone.

Soluble calcium salts, such as calcium chloride and calcium sulfate (gypsum), can be used on sodic soils. The calcium ions replace sodium ions and increase permeability and consequent leaching. Calcium chloride is more soluble than calcium sulfate and it has an immediate effect. Calcium sulfate, however, is less expensive.

The ammonium radical (NH_4^+) in ammonium nitrate and ammonium sulfate is effective in removing sodium from sodic soils. Anhydrous ammonia and urea are not effective due to a lack of anions. A combination of gypsum (80 percent), ammonium sulphate (10 percent), and calcium chloride (10 percent) has been found to be twice as effective as gypsum alone in preventing sodium from migrating up into topsoils spread over sodic minesoils.

Scrubber waste from power plants using limestone as the scrubbing agent also is effective for treating sodic soils. The addition of 10 percent ammonium nitrate or ammonium sulfate doubles its effectiveness.

Saline Soils

Saline soils, soils with basic salts other than sodium, can be treated with acid-forming chemicals and leaching. Sulfur, sulfuric acid, iron sulfate, aluminum sulfate, and lime sulfate are usable. However, adding these amendments to saline soils that do not contain alkaline earth carbonates may make the soils too acidic.

Organic Materials

Organic amendments can benefit plant establishment, especially on minesoils whose physical, chemical, and biological properties are unfavorable for the growth of vegetation. Adding organic materials can decrease bulk density of the minesoil and increase water infiltration and retention. Chemically, organic amendments can reduce acidity, increase cation exchange capacity, and add plant nutrients. Irrigating extremely acid spoils with sewage effluent, for example, leaches toxic chemicals out of the rooting zone, dilutes concentration of salts, provides nutrients to plants, and lowers surface temperatures. Some organic materials also provide an energy source for beneficial soil microorganisms and soil fauna.

Many metals, such as aluminum, iron, chromium, lead, and copper, form water-insoluble complexes with fulvic acids in soil organic matter. Adding organic matter to spoils can reduce the availability of the metals over time. Management practices that would lead to the destruction of soil organic matter at a later date would tend to release these metals again.

Organic amendments that have been tested and used on mined areas are mostly agricultural, industrial, municipal, residential, and forestry-related wastes or residues. They include such products as barnyard and poultry manures, sewage sludge and effluent, mushroom compost, paper mill sludge, composted garbage (solid municipal wastes), leaves, and combinations of these materials, such as garbage or leaves mixed with sewage sludge. Crop residues, such as straw, and residues, such as bark and wood chips, from sawmills and wood-conversion plants have been used both as soil amendments and as mulches.

Factors influencing rates of application of the different organic materials include the purpose for which they are applied, physical and chemical properties of the minesoil, depth of incorporation, and cost of obtaining and applying the materials. Suggested rates of application for some of the materials are barnyard manure and composted garbage, 15 to 30 tons per acre; leaves, 2 to 4 tons per acre (air dry); sewage sludge and effluent, volumes equivalent to 20 to 50 tons per acre of dry matter; paper mill sludge and mushroom compost, 50 to 100 air-dry tons per acre.

Several factors affect the economics of using waste and residue products, especially the costs of processing, transportation, and application. For such materials as sewage effluent, special distribution and application equipment entails high initial investment and costly maintenance. The economics of using waste or residue materials in reclaiming mined land should be evaluated in terms of costs and benefits both to the producers of the wastes and to those using it for revegetation purposes.

The incorporation of some organic materials, such as animal manure and composted sewage sludge, adds plant nutrients to the soil. However, incorporating materials that are not composted and are high in cellulose, such as whole-tree chips, will cause a deficiency of nitrogen to plants during the decaying process, so additional nitrogen fertilizer must be applied for the benefit of the vegetation. Where establishment of herbaceous vegetation is concerned, a rule of thumb is to add an extra 15 to 25 pounds of nitrogen for each ton of high cellulosic or noncomposted organic material that is incorporated into the soil. This extra nitrogen usually is not required where organic materials are applied on the surface as mulch.

Once a good organic matter reservoir is established in a soil, maintenance fertilization for nonagricultural use probably will no longer be necessary. The soil organic matter serves as a nutrient reserve, and is especially important as a nitrogen sink. The microorganisms responsible for "driving" the nutrient cycles, in which plant nutrients are recycled by a variety of organisms including plants, use the soil organic matter in part as a source of energy.

Microbiologic Materials

Microorganisms are essential to the establishment of permanent vegetation on mined lands. Although not an amendment in the sense of fertilizer or lime, some types of microorganisms can be added artificially to plant materials or to the soil to aid plant establishment and growth. For example, inoculating legume seeds with *Rhizobium* bacteria ensures that the legume plants will become effective nitrogen-fixers. Similarly, under natural conditions, most plant species depend greatly on a symbiotic association with mycorrhizal fungi. The survival and growth of pine on some mined areas have been enhanced by inoculating the seedlings with *Pisolithus tinctorius*, an ectomycorrhizal fungus that is tolerant of high temperatures and acid conditions. Spores of this type of fungus, produced above ground in mushroom-like structures, are disseminated by wind and readily form an association with pine seedlings under natural conditions. Seedlings can be artificially and more quickly inoculated by applying fungal spores directly to their roots just before planting, or by growing them in artificially inoculated nursery beds. Incorporating spores on the seed coat of conifer seed by pelletizing is another promising method of inoculation.

The endomycorrhizal fungi, another type of fungal associate, produce spores underground that are not as easily disseminated as the spores of ectomycorrhizal fungi. To inoculate plant seedlings with the appropriate endomycorrhizal fungal associate, the seedlings must be grown in nursery beds in which the fungal spores are naturally present. Because mycorrhizal fungi are naturally present in soil, spreading or mixing topsoil on the mine surface is one way to introduce these organisms into the minesoil. Where used as a mulch or soil amendment, bark that has had contact with soil is another probable source for the introduction of fungal spores into the minesoil. Spores of the endomycorrhizal fungi also can be spread through feces of soil-inhabiting rodents, such as field mice and voles. Thus, a vegetative cover that provides habitat for these rodents contributes indirectly to the spread of endomycorrhizal fungal spores that subsequently aid plant growth and natural plant succession.

Many of the microbial populations that are important and necessary in the decomposition and nutrient-cycling functions of ecosystems are introduced effectively with composted organic materials.

Irrigation

In dry regions, irrigation may be required for the establishment of vegetation. For most revegetation situations, this should be considered only as a temporary measure. The established plant community eventually will be required to persist in the absence of irrigation.

Irrigation may be a valid consideration where:

- It is essential to meet water requirement of plants.
- The mined area receives less than 10 inches of precipitation per year.
- Acquired water rights allow use of sufficient water for irrigation on the site.
- On-site water is available, inexpensive, and without encumbrance from local regulations in areas receiving more than 10 inches of precipitation yearly.

Information available on requirements for irrigation of agricultural soils may or may not apply directly to minesoils. It is known that the rate at which water can be applied is directly related to the permeability of the minesoil. Permeability is influenced by soil texture, especially clay content, by organic-matter content, and compaction. Water infiltrates sandy soils and soils high in organic matter more readily than clay soils and soils low in organic-matter. Sandy soils also have less water retention capacity than clay soils. Soil compaction reduces both infiltration rates and retention capacity.

There is little published information on watering regimes for mine soils and spoils. An example of watering regimes used on a surface mine in the West is given in Table 4. This example highlights the influence of clay content of the minesoil on water intake and retention. The heavy clay minesoils have a clay content of 50 percent or more, medium clay soils have 35 to 50 percent clay, and light clay soils less than 35 percent.

Density of plant cover will dictate how much water must be applied. Native plants in arid zones may be spaced widely under natural conditions as a consequence of root competition for water. Some ecologists argue that a similar spacing of similar species is adequate for reclaimed lands, while others argue that greater vegetation cover should be established and required due to the opportunity to create soils with greater water-holding capacity as part of the reclamation process. The dispute is not resolved. Regulatory requirements tend to make the question moot.

Water requirements of species must be considered in some cases. Seed of some warm season grasses, for example, require several days of water for germination. Three to four weeks later when a secondary-root growth phase starts, the plants need additional water to support root growth that may be at a rate of ½ inch per day.

Two methods of irrigation, sprinkler and drip, are most frequently used in revegetating surface mines. Available water, water quality, soil conditions, labor requirements and costs, and need to minimize evaporation are some factors to consider when choosing between the two methods. Table 5 summarizes some advantages and disadvantages of each method.

Table 4. Watering regimes on minesoils, Navajo Mine, New Mexico.

Minesoil type	*Duration (hours)*	*Frequency*	*Total Amount Applied*
Light clay content	8	Every other day	12 inches the first year; 2 inches the second year; none thereafter
Medium clay content	6	Every 6th day	12 inches the first year; 2 inches the second year; none thereafter
Heavy clay content	4	Every other day	12 inches the first year; 2 inches the second year; none thereafter

(System used: Laterals set 40 feet apart, with sprinkler heads 40 feet on the laterals; pressure-regulating valves aided in delivering about 1.8 gal/min—an application rate of 0.08 inch/hr)

From: USDA Forest Service, 1979.

Water Harvesting

Water harvesting is the practice of collecting runoff water from an area of land surface and concentrating it in a zone for growing plants. This practice may be useful where lack of precipitation is the major limiting factor to revegetation, and where irrigation water is scarce or irrigation is impractical. It is an appropriate practice especially in areas receiving less than 15 inches of precipitation per year. Snow and rain are collected by water harvesting and this can result in 2 to 3 times more biomass production in areas where water is collected than in areas where it is not collected.

The size of the area needed for collecting water depends on the amount, timing, and intensity of precipitation, soil permeability, and slope angle. Where precipitation is typically of high intensity and short duration, small collection areas will be needed because runoff will be substantial. Soils with low infiltration rates will dictate smaller sizes of catchment areas. The ratio of the collection area to the plant-growing zone area may be as high as 30:1 on some soils in some regions, but 3:1 to 6:1 is more typical on surface mines. Where pools of water form or gullies originate in the vegetation infiltration zones, the water-collection area may be too large. Accumulated moisture should readily soak into the plant-growing zone. The accumulation of salts is one potential problem on minesoils high in salinity.

Pitting, gouging, and contouring are acceptable methods for use on mined lands. The object of these methods is to increase runoff from the water-collecting zone and increase infiltration in the plant-growing zone. Long water-collection beds usually work satisfactorily only in flat terrain.

Soil sealers such as paraffin, silicone emulsion, and polyvinyl acetate have been used to slow infiltration in collection zones. Characteristics of the soils will determine whether such sealers should be used. A chemical sealer may be helpful in sandy soils. Sodic, clayey soils are self-sealing and chemical treatment is unnecessary. Mulches also may aid water harvesting by increasing infiltration and reducing evaporation in the plant-growing zone.

Disk plows have been used to prepare furrows or contour trenches for harvesting water on slopes. The contours should be spaced no more than 10 feet apart on slopes exceeding 15 percent. Furrows 1 foot deep and 15 inches wide are recommended. Large, multidisk plows can be used if every other disk blade is removed, and the largest possible disks are used. Construction of contour trenches on minesoils that tend to settle or are subject to piping may result in slope failure or increased erosion due to concentration of water.

Seeding Practices

Herbaceous species usually are established from seed; a few species of trees and shrubs, too, can be established successfully by seeding. Although proper selection of species is important, an equally important factor influencing the success of revegetation is adherence to the appropriate principles and practices of site and surface preparation and seeding.

Site and Seedbed Preparation

A suitable seedbed is required for the successful establishment of seeded vegetation. A suitable seedbed is one that provides microsites and conditions favorable for seed germination and seedling growth. An example of this is sometimes seen on mined areas where seeded vegetation is established in depressions left by tracks of crawler tractors, but few plants are found between depressions.

Broadcast seedings made on the surface in late winter and early spring sometimes are successful without mechanical preparation of a seedbed because the seed are "planted" by the alternate freezing and thawing (frost heaving) of the soil. Frequently, though, preparing a seedbed by mechanical tillage or scarification is required to break up crusted or compacted surfaces.

The final grading of resoiled areas is a form of surface preparation that may provide a suitable seedbed if the

Table 5. Advantages and disadvantages of drip and sprinkler irrigation systems.

Irrigation System	*Advantage*	*Disadvantage*	*Comment*
Drip	Uses ⅓ less water	Water with high levels of sediment will clog the lines unless well filtered	Also called trickle irrigation Plant densities will be less; this can be a disadvantage
	Evaporation is minimal	With water high in salt, deposits of salt can build up around the emitter openings	Adequate filtering system crucial
	Amounts of water can be placed directly where wanted	Needs more maintenance than a sprinkler to check filtering system	Quality of water (sediment, salinity) a factor
	Especially useful on steep slopes, under power lines, (because it is safer) between buildings, on critical areas	Labor intensive Less easy to move Shorter life span than sprinkler system	Three types of emitters: spitter (puts out a spray); single (puts small in local place); and bi-wall (plastic tubing with pin-pick opening to emit water)
	Moves salts away from plant roots	Higher costs than sprinkler	A portable drip system using a 500-gallon tank has been developed by the Rocky Mountain Forest and Range Experiment Station, Albuquerque, NM
Sprinkler	Less Filtering needed	More evaporation will occur	Choose between solid set or movable
	Less expensive than drip	Need larger water supply	High plant densities possible
	Less labor intensive	Frequency of application higher than drip	
	Longer life		
	Easier to move, more flexible		

From: USDA Forest Service, 1979.

seeding is done immediately on the newly graded surface. Some grading practices, however, produce surfaces that are detrimental to vegetation establishment. Grading dry materials to a very fine or smooth finish may produce surface conditions where there is little or no microtopographic relief or microclimatic modification to protect and enhance survival of the newly sprouted plants. Grading minesoils when they are wet may result in a compacted or crusted surface similar to that of pavement. Revegetation problems are more likely to result from excessive grading and "overworking" minesoils than from minimal grading and tillage.

Earth materials that contain a relatively high content of clay and silt, such as some topsoils, subsoils, and parent material used to cover mine spoils, are especially susceptible to compaction by earth-moving and other equipment. The growth of plants, especially trees, is adversely affected in such compacted soil conditions. This adverse effect on tree growth has persisted for more than 30 years on some graded mined sites in the Midwest. Conversely, in minesoils where coarse particles predominated, grading was beneficial to plant establishment and growth.

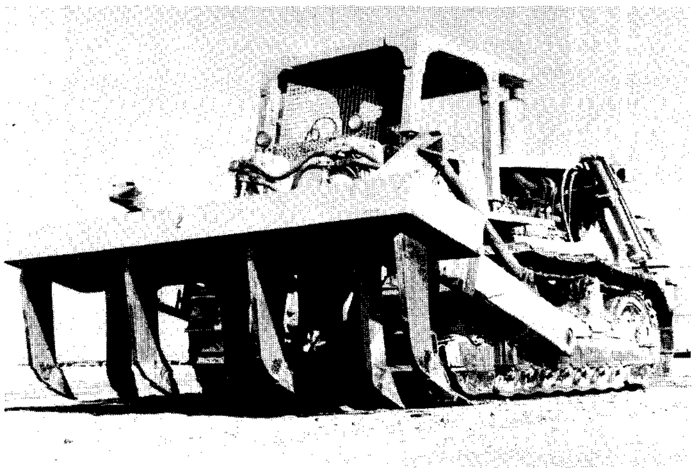


Figure 4. Subsoiler.

Figure 5. Chisel plow for preparing a seedbed or incorporating lime.

A number of implements can be used to ameliorate compaction caused by earth-moving and grading equipment. For primary tillage on compacted minesoils, deep rippers pulled by large bulldozers are very effective. These can rip heavy and rocky minesoils to a depth of 3 feet. Deep ripping may be most useful wherever minesoils have been placed with a pan scraper. Deep ripping is not advised where it will bring highly acid or alkaline materials to the surface. Avoid deep ripping on slopes where rapid infiltration of water will create an unstable mass prone to slippage and landslides. Standards (teeth) on the ripper should be placed a distance apart approximately equal to the depth to be ripped. Minesoils always should be ripped on the contour, and only when relatively dry. Wet soils may reseal quickly because the ripper will make only a thin slit through wet material. Also, heavy equipment traveling over ripped areas on wet soil may cause resealing of the slits.

Subsoilers, originally designed for renovation of agricultural lands with deep clay pans, may be useful on some relatively stone free minesoils (Figure 4). Subsoilers differ from rippers in that they have less tendency to bring materials to the surface or mix soil horizons. The largest subsoilers can rip to a 9-foot depth, but shallow ripping (12 to 18 inches deep) is more common. Avoid subsoiling where it will penetrate into sandy or other pervious layers in which water tables will drop rapidly during drought.

Several implements are useful for shallow ripping and breaking up surface compaction. Chisel plows have several arms with chisel points that can rip to a depth of 12 inches. The arms operate against a heavy spring that allows them to ride over large surface and subsurface rocks (Figure 5). Small to medium-size rocks, though, may be pulled to the surface and these may interfere with machinery operation in some postmining land uses. Chisel points can be expected to wear rapidly and require frequent replacing in stony materials, especially in sandstones. Chisel plows leave a seedbed smooth enough to accomodate drill seeders pulled by farm tractors, and rough enough to catch broadcasted seed and trap moisture and runoff water. Chisel plows will break compacted layers that are impenetrable by disks. Chisel plowing is one of the most useful tillage operations in revegetating minesoils.

Disking often is used to break up surface crusting (Figure 6). It also is used to incorporate lime and to mix an established surface vegetation cover into the soil. Tandem disks and offset disk harrows produce a mixing affect, not a simple inversion. They produce a good seedbed but it may be more susceptible to erosion than a seedbed prepared with a chisel plow. Large rocks will cause the entire disk or an entire section of disk to rise out of the soil, so it may be an impractical tool on some minesoils.

Roller harrow-packers, known also as cultimulchers, cultipackers, corrugated rollers, or soil pulverizers, have a front packer that breaks up clods, harrow teeth to bring up more clods, and rear packers to break up the newly surfaced clods. This implement pulverizers, and firms soils and closes air pockets, but has limitations on stony minesoils. The seedbed procedure is especially effective for preparing a seedbed to be planted with a drill.

Spring-tooth harrows are able to work soils to a depth of 3 to 6 inches. They smooth the surface, break up clods, and close air pockets. Harrowing is useful after rippers have been used. The spike-tooth harrow is similar in action but may be somewhat less effective than the spring-tooth harrow.

"Front blading" and "back blading" with a bulldozer are sometimes used to prepare a seedbed surface, but neither procedure is as effective as using implements designed for tillage, nor do they alleviate soil compaction. With front blading, the dozer tracks leave depressions that collect water and favor seed germination and seedling growth. "Tracking in" by running a dozer (with blade lifted) up and down slopes is one method for preparing a seedbed on slopes too steep for other equipment. Dragging a heavy chain or anchor chain, either plain or preferably one with spikes welded across the links, over the surface is another method for making a seedbed on steep slopes. This procedure requires a roadway at the top of the slope for travel of the prime mover.

The intensity of tillage and surface-preparation methods needed at a given site will depend on type of soil, post-mining land use, and climate. An intensively prepared seedbed may be suitable for some agricultural uses on replaced topsoils. In other situations, minesoil tillage that leaves a roughened surface, such as done with one pass of an offset disk or chisel plow, may be preferable. Precipitation is trapped and held more effectively on a roughened surface than on a smoothly prepared one.

Where compatible with the planting season and where needed, tillage should be done as soon as possible after slopes are shaped and grading is completed. Unless ill-advised because of climatic constraints, seeding should follow immediately, especially broadcast seedings. If necessary, a temporary cover can be established that later can be tilled under and replaced by more desirable and permanent species.

In summary, the general sequence of site preparation for seeding and planting is (1) rip where needed to break compaction; (2) apply lime where needed; (3) disk, harrow, or chisel plow; (4) apply fertilizer; and (5) harrow in fertilizer where experience suggests it is necessary (in some cases fertilizer can be applied before step 3).

Methods of Seeding

Drilling and broadcasting are the two basic methods of planting seeds. In drilling, seeds are dropped from a container mounted on an implement called a drill into holes or furrows formed by that implement; the seeds are immediately covered with soil (Figure 7). Broadcasting scatters seeds on the ground surface where they may or may not be covered later by mechanical operations or by natural sloughing of the soil. Broadcasting includes hydroseeding and aerial seeding, and sometimes is done by hand on small areas (Figure 8).

Drilling is considered the superior method of seeding where site and soil conditions permit. It controls rate of seeding, distributes seed uniformly, and assures that seed is covered to the proper depth for germination and establishment. Some drills have packer wheels that firm the soil over the seeds. Adequate coverage of broadcasted seed may be uncertain unless followed by some form of mechanical treatment. Where the seedbed was tilled recently and is loose, natural sloughing of soil may cover most of the seed. But adequate or timely coverage by natural sloughing is not always reliable, particularly in arid climates. Seeds left uncovered may germinate on the soil surface when moisture and temperature conditions are favorable, but later die when these conditions become unfavorable for continued seedling growth. Uncovered seeds also may be pilfered more readily by birds and small mammals. To compensate for these anticipated losses, more seed is used in broadcast seeding than in drilling. However, equipment costs and time requirements generally are greater for drill seeding. One exception may be where seed is broadcast with a hydroseeder.

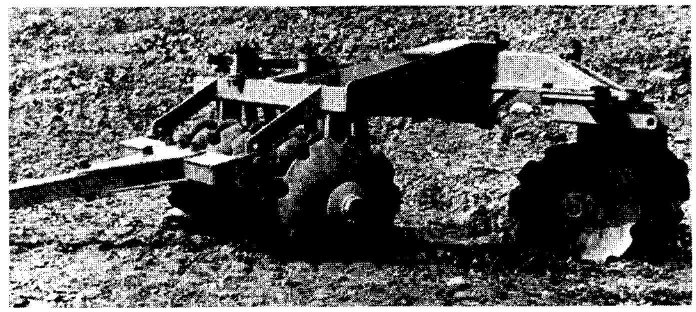


Figure 6. Offset disk harrow for preparing the seedbed or incorporating lime. (Photo courtesy of Rome Industries)

Figure 7. The rangeland drill.

Drills. Seeding with drills is limited to sites that can be traversed with equipment normally used on farms and rangelands. It is advisable to operate drills primarily on the contour because the furrows formed by the drill will help trap precipitation and reduce runoff and erosion, whereas furrows up and down slope can accelerate erosion. On slopes too steep to drill on contour, broadcast seeding is a logical alternative.

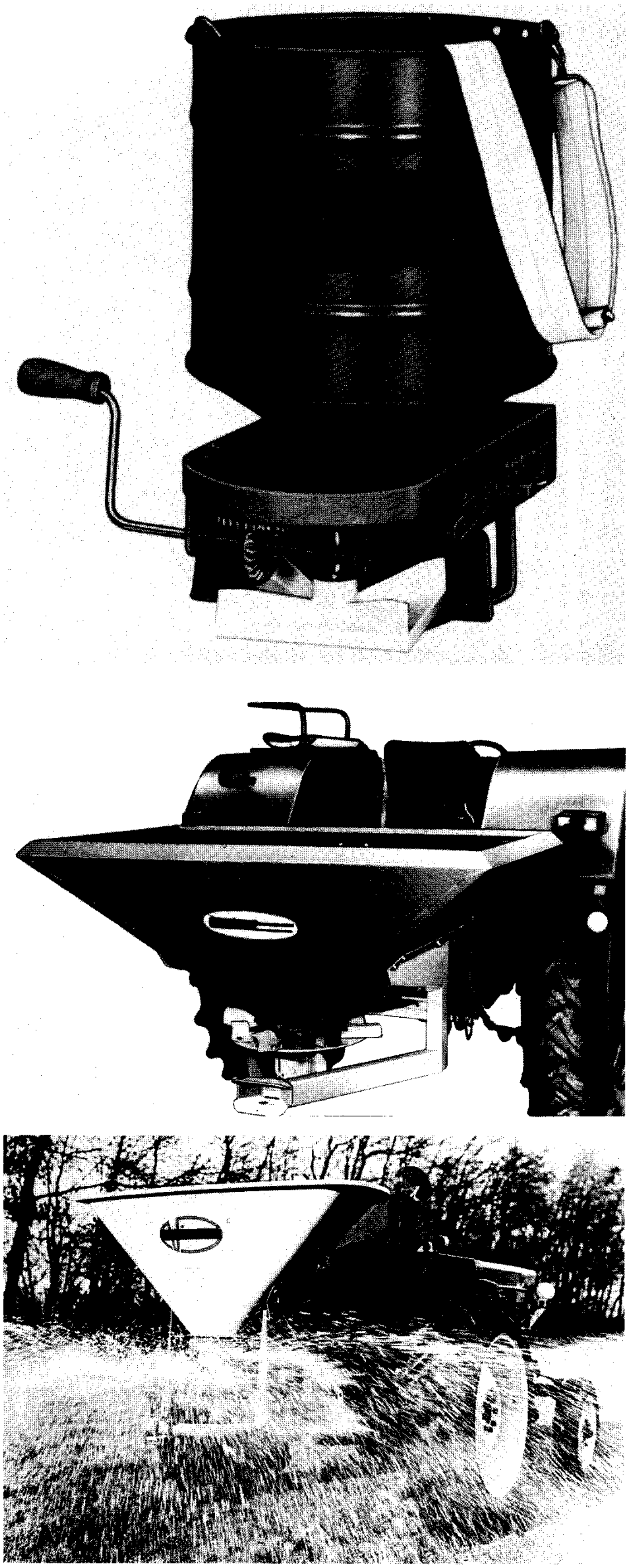


Figure 8. (Top) Hand-operated rotary spreader, (middle) rotary spreader, (bottom) oscillating pendulum spreader.

Several types of drills are on the market, any one of which may be suitable for a particular situation. However, some are generally more suitable than others for mined-land reclamation. The selection of a specific drill may depend mainly on its capability to perform the necessary seeding task on the site and soil conditions present. For example, use of standard farm-type grain and grassland drills may be limited to topsoiled sites relatively free of stones and debris; whereas the rangeland drill (Figure 7), seeder-cultipacker drill, and several others are more rugged and better choices for seeding in rough terrain and stony soils. Some drills are designed to handle light, chaffy or fluffy seeds that will not feed through the metering mechanism on most standard drills. A problem may develop in finding one drill capable of satisfying several special requirements.

Broadcast Seeders. Seed may be broadcast by several types of seeders, including centrifugal-type broadcasters, field distributors, hydroseeders, fan or air-blast seeders, and by aircraft.

The centrifugal-type broadcaster, also called end gate seeder, provides an economical way of broadcasting most kinds of seeds as well as granular and pelleted fertilizers. These seeders are available in a variety of sizes and capacities and have an effective spreading width of 20 to 40 feet, depending on the physical characteristic of the seeds. Models that mount on a tractor or truck and larger pull-type models are available. Small hand-operated models are useful on small areas unreachable by mechanized equipment.

Hydroseeders broadcast seed in a high-pressure stream of water (Figure 9). Fertilizer and mulch also can be mixed with the water and seed and applied at the same time. The hydroseeder is especially useful for seeding steep slopes and highwalls that cannot be reached with other types of seeders. It is less efficient than centrifugal-type seeders on areas where the latter can be used. Some potential disadvantages of the hydroseeder are that a source of water must be available near the seeding job, and a considerable amount of time is required to fill the tank with water. Where mulch is added to the seed-water mix, only a relatively small area can be covered with each tankful. The agitation system in some types of hydroseeders will damage seeds of some species. On the other hand, the germination potential of seeds with hard coats may be enhanced by scarification caused by the agitator system.

A field distributor is an implement similar in appearance to a drill, but it does not have furrow openers or seed-covering attachments. It has metered openings along the full length of the seed box from which seeds fall to the ground.

Fan or air-blast seeders use forced air to blow seed or fertilizer onto the target area. These would be useful mainly on smaller steep sloping areas that cannot be covered with centrifugal-type seeders.

Aircraft seeding is especially useful on large areas and on sites where the terrain is inaccessible or too rough to use land-going equipment. Seeding by aircraft requires a power-driven, seed-metering device for dispensing seed because hoppers that dispense by gravity usually are inadequate. Both fixed-wing and helicopter aircraft can be used. Helicopters are particularly effective because the downward rotorwash blows seed into cracks, under the edges of rocks, debris, etc., where the microclimate may be better for germination and establishment. With large seed, such as acorns, seed shatter may occur. Aerial seeding requires considerable ground-support equipment and personnel, and is subject to delay when strong winds will cause uneven seed distribution.

It is important to remember that success with broadcast seeding, by whatever means, is largely dependent on a suitable seedbed and may be further enhanced by efforts to cover the seed mechanically after broadcasting.

Time of Seeding

The time to seed or plant is influenced by such factors as climate and seasonal weather patterns, seasonal growth patterns and moisture requirements of the planted species, completion of mining and surface preparation, soil dry enough to allow use of equipment, and potential for frost heaving and erosion. Usually, the best times for planting precede or coincide with periods of precipitation that are of sufficient duration to allow the planted vegetation to become established. Revegetation usually is more successful where final shaping of the mined land is timed to coincide with seasons most conducive to planting and seeding. These seasons may vary somewhat in different regions of the country. It is advisable to obtain this information from local agricultural agencies and other knowledgeable sources.

Seed Quality

The use of high-quality seed that has been tested and tagged properly will help ensure the successful establishment of vegetative cover. Seed quality can be determined from information listed on the seed tag (Figure 10). Two of the values listed on the seed tag—pure seed and germination percentage—are used to determine pure live seed (PLS). Pure live seed is useful for figuring proper seeding rates and the real cost of seed.

To calculate PLS, multiply the percent of pure crop seed by the germination percentage and divide by 100. For example, if a batch of seed contains 95 percent pure seed and has 80 percent germination, the percentage of pure live seed (PLS) is 76; (95 x 80) ÷ 100 = 76 percent. This means that in a quantity of seed weighing 100 pounds, only 76 pounds have the potential to germinate.

When purchasing seed, comparative pricing should be based on PLS. This is especially important when buying species that inherently differ in purity and germination between seed lots. To determine the cost per 100 pounds of PLS, divide the cost per 100 pounds by the percent PLS and multiply by 100. For example: Lot A of fescue seed costs $35 per 100 pounds and has 89 percent PLS; ($35 ÷ 89) × 100 = $39.33, the cost per 100 pounds of PLS. Lot B of fescue seed costs $31 per 100 pounds but has only 68.4 percent PLS; ($31 ÷ 68.4) × 100 = $45.32 per 100 pounds of PLS. Although its bulk price was less, seed Lot B actually costs more than Lot A for an equal amount of PLS.

Other items that describe seed quality, such as the percentage in weight of weed seed and the name and number per pound of noxious weed seed, are listed on the seed tag. The presence of certain noxious weed seed may be so potentially harmful that high germination would not be the most important consideration in seed quality. The date of test also should be noted to be sure that the seed germination has been tested recently.

Using seed of unknown quality presents an added risk in establishing vegetation. However, this may be necessary and justified where locally collected seed of native plants are added to the seeding mixture to increase species diversity. Do not depend on seed of unknown quality to be the major contributor to a stand of vegetation, particularly where the vegetational cover is essential for controlling erosion.

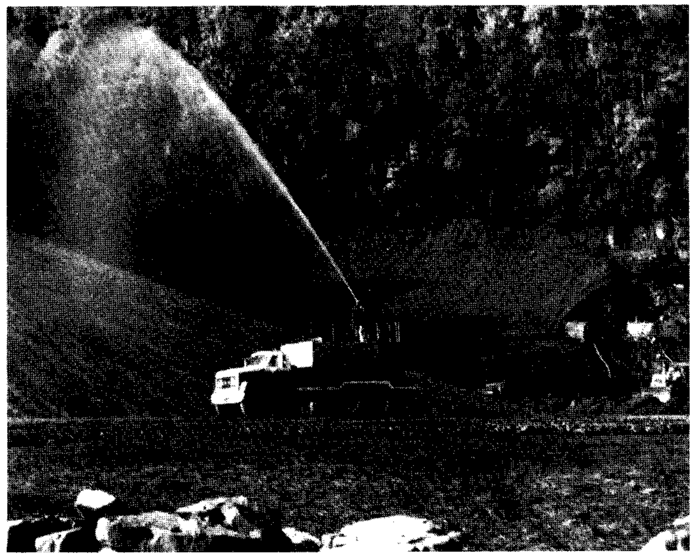


Figure 9. The hydroseeder.

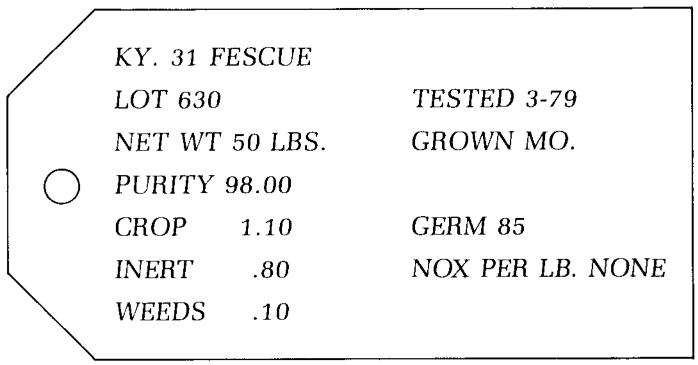


Figure 10. Seed tag.

Seeding Rates

Seeding rates recommended in this handbook are expressed in pounds per acre PLS. The use of PLS seeding rates rather than bulk seeding rates will ensure that an adequate amount of viable seed is sown. This is especially important for proper seeding of species, such as some of the native grasses, that often have relatively low purity and germination. Seed often is priced on the basis of bulk weight, though many dealers now price seed on a PLS basis. In the latter case, simply purchase the needed amount of PLS. Where necessary to calculate the amount of bulk seed needed to meet the recommended PLS rate of seeding, divide the recommended PLS seeding rate by the percent PLS of the seed to be purchased and multiply by 100. For example, if a batch of switchgrass seed has 60 percent PLS, and the recommended PLS seeding rate is 12 lb/acre, then $(12 \div 60) \times 100 = 20$ lb/acre bulk seeding rate. Obviously, if only 12 pounds of switchgrass seed were sown, not nearly enough viable seed would have been sown to meet the seeding recommendations.

The PLS seeding rates suggested here usually are sufficient for vegetating minesoils that have properly prepared seedbeds and are adequately fertilized, limed, and mulched. Sowing additional seed seldom compensates for failure to prepare a seedbed or apply needed amendments. Seeding at too high a rate can cause seedling competition and result in a reduced stand, especially in drier environmental and climatic situations and in well-prepared seedbeds. In seed mixtures of herbaceous species, the temporary species especially should not be sown in excess of recommended rates because they may retard or prevent establishment of the permanent species. In situations where temporary species are sown alone for growing mulch in place, the use of additional seed may be justified.

Inoculation of Legume Seed

Seed of herbaceous legumes should be inoculated with the appropriate strain of rhizobia. The value of inoculating seed of leguminous shrubs and trees is uncertain because some of these species have been established successfully from noninoculated seed. Inoculants are commercially available for most species of herbaceous legumes; however, for some of the woody legumes and less common or seldom used herbaceous legumes, inoculum must be specially prepared by the manufacturer.

There are several methods of inoculating seed. For dry seeding, the inoculant can be mixed with lightly moistened seed just before sowing. The inoculant should be applied generously—using even more than that recommended by the manufacturer. Moistening seed with a "sticker" such as sugar mixed with water, molasses, or synthetic gums helps bind the inoculum to the seed and extends longevity of the rhizobia. Soil implant inoculants are available whereby the rhizobia is placed in the soil instead of on the seed. Preinoculated legume seed can be purchased from some seed dealers. Reported success of implants and preinoculated seed is varied.

When seeding with a hydroseeder, the inoculant is added to the slurry just before it is spread. If the slurry includes fertilizer, the inoculating bacteria may be killed by high acidity (low pH) caused by the fertilizer. To reduce loss of the bacteria, the slurry pH should be kept above 5.0 and spread as soon as possible after mixing. Where slurry pH is below 5.0, hydrated lime can be added at 100 pounds for each 1,000 gallons of water to lessen the effect of the acidity. For hydroseeding, inoculants should be added at double the amount recommended for dry seeding.

Commercial inoculants are stamped with an expiration date because the viability period of the packaged rhizobia is limited. Inoculant with an expired date should not be used. The environment in which inoculant is stored also affects its viability. High temperatures will destroy it, so beware of buying and using inoculant stored or displayed in abnormally warm places such as in attics or next to stoves. Inoculant should be kept in a cool place. Partially used packages should be resealed tightly. Use inoculant only on the legume species for which it is specified.

Planting Woody Species

The establishment of woody species is important to forestry and wildlife-habitat land uses. Given sufficient time, woody species often will become established by natural secondary succession, especially in humid regions where the native vegetation is forest. However, the establishment of forests with commercial value may be extremely slow by natural processes. Artificial planting of trees and shrubs may be the surest way to establish fully stocked stands of desired species, especially trees for commercial harvest. On the other hand, the early and intermediate stages of natural succession may be desired because they provide habitats for a variety of wildlife species.

In most of the coal-mining areas of the Western Region, trees are a small component of the natural vegetation and sometimes are planted mainly to impart an esthetic value to the landscape. Shrubs more often are desired and planted because they are an important component of some vegetational types and provide habitat and forage to wildlife and domestic livestock.

Woody species most often are established by planting bare-root seedling grown in nurseries or seedlings grown in containers in greenhouses. A few species of shrubs and trees can be established successfully by direct seeding and from cuttings. Transplanting individual plants or clumps from the wild (wildings) to another site may be useful for certain situations, such as for establishing species that are difficult to start from seed or that produce poor seed crops.

Factors that influence the success of planting and that can be controlled by the reclamation manager or technician include the (1) quality of planting stock, (2) care of planting stock, (3) method of planting, (4) time of planting, (5) competition from herbaceous vegetation, and (6) soil compaction. Heeding and using proper establishment procedures is as important as selecting the appropriate plant species.

Nursery-Grown Seedlings

Bare-root or nursery-grown stock usually is grown in nursery beds for 1 to several years. After that, the plants are lifted while dormant, the soil shaken from their roots, and the plants packaged for cold storage or for immediate shipment to the buyer. Bare-root seedlings are easier to handle, ship, store, and plant than container-grown plants.

Most native and introduced trees and shrubs can be grown and planted as nursery stock.

Nursery-grown planting stock often is defined in terms of age such as 1-0, 2-0, 2-1, and so on. A 1-0 seedling is produced in 1 year, lifted from the seedbed, and is ready for immediate planting in the field. A 2-0 seedling is left in the seedbed for 2 years. A 2-1 seedling is grown for 2 years in the seedbed, then transplanted and grown 1 year in a transplant bed before it is lifted for field planting. The sum of the two numbers is the age of the seedlings.

Plantable stock of many of the suitable species is produced in 1 year. However, the size of planting stock can vary because of different practices among nurseries and with different seasons in the same nursery. The quality of planting stock should be judged mainly by the size and balance of the seedlings rather than solely by age. Stem diameter and length and weight of roots in relation to length and weight of tops generally are considered the best criteria for judging stock quality. Root and top pruning, a practice for adapting seedling size to different methods of planting, also affects stock quality.

Generally, larger stem diameters (within limits) mean better survival of seedlings. For seedlings of most conifers and hardwoods, a minimum stem diameter of 0.1 to 0.15 inch (2.5 to 4 mm) is recommended. The maximum stem diameter for planting is limited or determined by the length and spread of roots that can be accommodated by the method of planting. For most planting jobs, roots are pruned to standard lengths, usually 6 to 8 inches, to accommodate planting with planting bars and mattocks. If the diameter and length of top are excessive in proportion to the length of pruned roots, an imbalance in the physiological processes of the seedling could greatly decrease its chances for survival. Seedlings of most hardwoods can be top pruned with no significant effect on survival. Top pruning can facilitate packing, shipping, and handling of hardwood seedlings. Top pruning is not advised for conifers.

Planting-stock standards for the Central States Region were developed by the USDA Forest Service for tree species commonly planted on mined lands (Tables 6-7). For conifers, the standards are based on stem diameters (at the ground line) and the relation of top lengths to root lengths after pruning. For shortleaf pine, for example, the recommended minimum stem diameter is 0.15 inch; if roots are pruned to 6-inch lengths, the tops should be longer than two-thirds the length of the roots (4 inches) and shorter than 8 inches. For hardwoods, the standards are based on stem diameters only; maximum stem diameters are prescribed only if roots are pruned to lengths of 8 inches or less.

Selection and use of planting stock inoculated with the appropriate mycorrhizal associates is another factor to consider. The species of mycorrhizal fungi normally present in nursery beds may not be adapted to the inhospitable environment of minesoils. In addition, fumigation and fertilization practices used in many nurseries were found to retard or inhibit development of the beneficial fungi. As additional knowledge is gained about the mycorrhizal fungi and other beneficial microorganisms, nurseries will have opportunity to develop or adapt techniques for inoculating and producing planting stock with the mycorrhizal species that are most beneficial for best survival and growth of seedlings on mined areas.

Container-Grown Planting Stock

Plants grown in containers have some advantages over bare-root stock for planting on harsh sites and in areas of low or erratic precipitation. Container stock usually can be grown more quickly by suppliers and can be available for planting in seasons when bare-root stock is unavailable. Root systems of container stock are better formed, not subjected to the shock of lifting and pruning, and are better protected during transplanting than those of bare-root seedlings (Figure 11). For some species, survival is nearly always better for container than for bare-root stock.

Disadvantages of container plants include higher production costs, bulky and awkward handling, and proper storage facilities and daily care required to maintain them from time of delivery until field planting is completed. Although bare-root stock is nearly always less costly to

Table 6. Planting stock standards for hardwoods planted on surface-mined land in the Central States.*

Species	*Stem Diameter at Ground Line* Minimum	*Stem Diameter at Ground Line* Maximum (For roots pruned to 8 inches or less)
	Inches	Inches
Maple, silver	0.15	0.40
Ash, green and white	0.10	0.35
Walnut, black	0.20	0.35
Sweetgum	0.15	0.40
Tulip poplar	0.25	0.35
Osage-orange	0.15	0.40
Sycamore	0.10	0.35
Cottonwood	0.15	0.40
Oak; bur, northern red, and chestnut	0.15	0.40

*From Limstrom, G. A., 1960.

Table 7. Planting-stock standards for conifers planted on surface-mined land in the Central States.*

Species	*Minimum Diameter of Stem at Ground Line*	*Allowable Range in Length of Tops* For Roots Pruned to 6 Inches	*Allowable Range in Length of Tops* For Roots Pruned No Shorter than 8 Inches
	Inches	Inches	Inches
Eastern redcedar	0.15	4-6	6-12
Jack pine	0.10	4-6	6-12
Shortleaf pine	0.15	4-8	6-12
Red pine	0.15	4-6	6-12
Pitch pine	0.15	4-8	6-12
Eastern white pine	0.15	4-8	6-12
Loblolly pine	0.10	4-6	6-12
Virginia pine	0.10	4-6	6-12

*From Limstron, G. A., 1960.

grow and handle, the better survival rate of container-grown plants of some species will economically justify using container plants of those species.

Container-grown seedlings are more often used for planting on mined lands in the Western Coal Region than in eastern regions. But, even in the East, container seedlings have been used to extend the planting season into late spring and early summer. In a test in Tennessee, container-grown seedlings planted on July 1 had 87 percent survival, whereas bare-root stock that had been kept in refrigeration had 3 percent survival. In other plantings made in the usual early-spring planting season, survival of container-grown tree seedlings was no better than survival of bare-root seedlings.

Not all containers are suitable for mined-land plantings. Tube containers made of plastic, for example, are more susceptible to frost heaving than peat pot and peat-pellet containers. For planting in arid regions, tube containers at least 10 inches, and preferably 24 inches long, and 2 to 3 inches in diameter provide the seedlings a better chance for survival than shorter and smaller containers.

Planting Methods

Irrespective of the method of planting, bare-root stock should be protected from exposure to sun, heat, and dry-

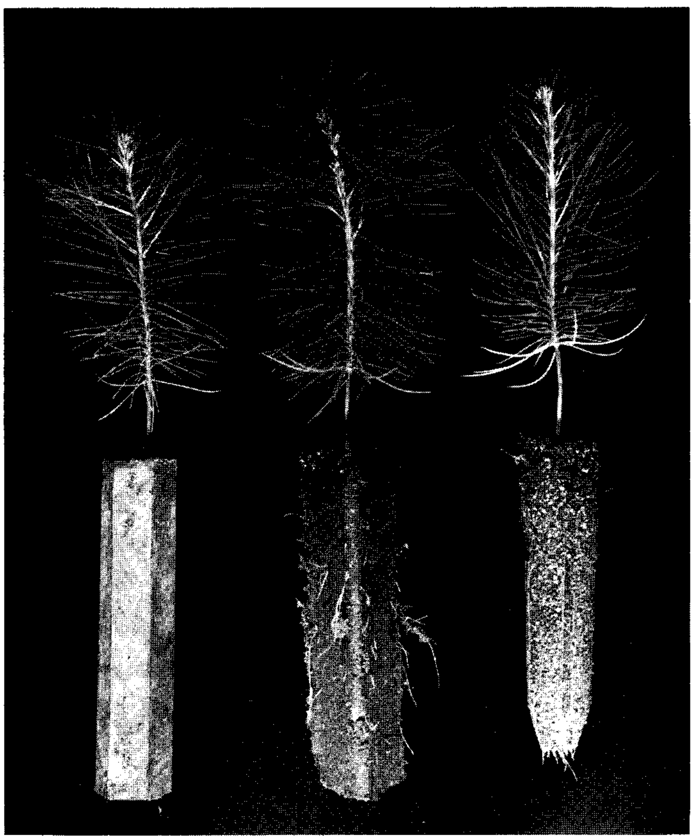


Figure 11. Lobolly pine seedlings grown in three types of continers: (A) a biodegradeable plastic tube, (B) a peat moss vermiculite molded block, and (C) a plug from Styroblock 2.

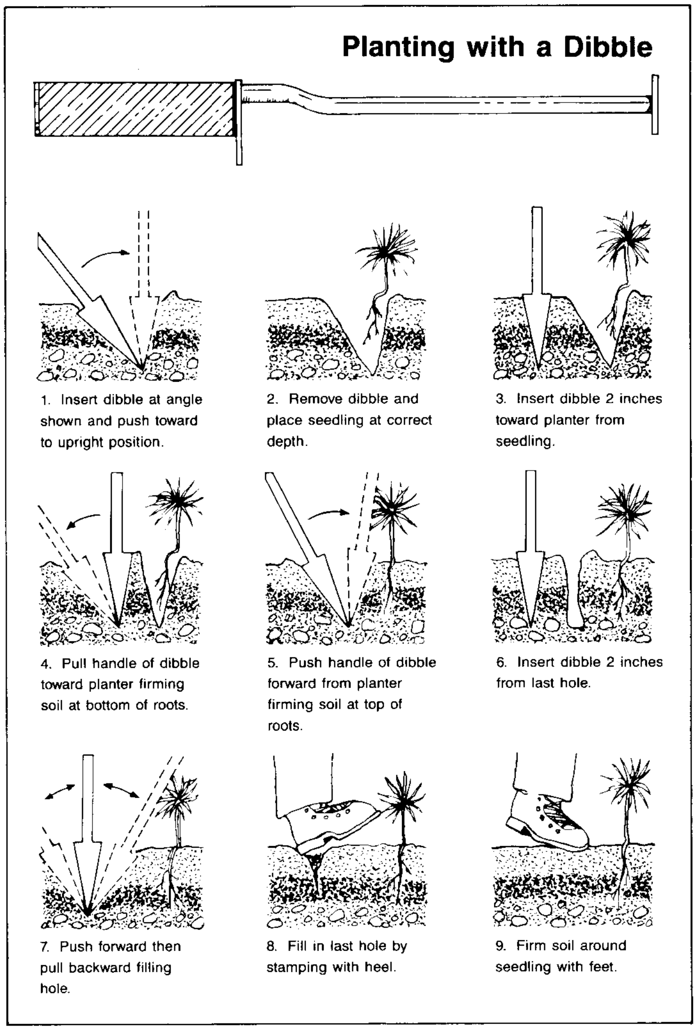


Figure 12. Planting tree and shrub seedlings with a dibble (redrawn with permission from John Wiley & Sons, Inc. and Alabama State Forester).

ing during shipment and delivery to the planting site. Seedings should be planted as soon as possible. If necessary to keep stock several days before planting, moisten unopened bundles and store in a cool, shaded place. For seedlings that cannot be planted within 2 weeks after delivery, the bundles should be opened, inspected, moistened, and "heeled in" or placed in cold storage at 34° to 38°F. Stock of most species can be held safely in cold storage for at least 3 to 4 weeks.

Containerized plants produced in a greenhouse must be "hardened off" before planting to enable them to resist cold, heat, or desiccation after planting. To accomplish this, the plants can be taken from the greenhouse and placed for 2 to 3 weeks in a sheltered outdoor location where they are exposed to cooler or warmer temperatures, depending on the season, and less watering and then planted directly on the mine site. Or they can be hardened off, placed in refrigeration at 43°F, and planted at a later date. Once the plants are delivered to the field site, they need proper storage and watering facilities, and daily care until field planting is completed. Irrigation may then be needed in arid climates to help establish the plants.

Bare-root seedlings of trees and shrubs can be planted by hand or by planting machines. With hand planting, a planting bar (dibble) or mattock (planting hoe) are most often used to make the holes (Figures 12-13). The planting bar is a better choice for stony or compacted minesoils. Seedlings should be planted to the same depth at which they were growing in the nursery and the soil pressed firmly around the planted seedling. The planting hole should be large and deep enough so that the seedling roots can be spread out and not bunched or doubled under (J-rooted). Seedlings so planted may survive for several years, but inadequate or deformed root systems will develop that may cause trees to die or fall over well before a usable size is reached.

While planting, seedlings must be kept moist in a canvas planting bag or in a bucket containing enough water to cover the roots (Figure 14). Tree roots exposed to direct sunlight or drying can be damaged or killed quickly. Seedling roots are sometimes coated with kaolin clay to retard root drying while planting. To make the coating, mix 100 pounds of kaolin clay in 25 gallons of water. Dip the roots in the clay slurry. Planting trays or buckets, but not planting bags, are recommended for carrying coated seedlings.

Holes for hand planting container-grown stock can be made with mattocks and planting spades, but specially designed plug dibbles and planting tubes that punch holes the size of the seedling container usually are more convenient and efficient to use. A hand-held power auger also functions well for digging holes for container and bare-root seedlings except in stony and heavy clay soils.

Planting by hand is necessary on steep slopes, small areas, and where surface shaping and site preparation treatments would be damaged and made ineffective by machine planters. Hand planting usually is done with crews of a few to several planters. For larger crews, at least one person should be responsible for caring for planting stock and distributing it to the planters. On steep slopes where rocks can roll or slide, no planter should work directly below another.

Tractor-drawn, mechanized planters are useful for planting bare-root seedlings on large, relatively level areas that are reasonably free of stones (Figure 15). Usually, 15 to 20 percent is the safe maximum slope for machine planting on contour. For safety, steeper slopes, up to 30 percent, should be planted up and down slope; however, furrows running up and down slope can create channels for initiating gully erosion. Care should be taken that the machine covers the furrow sufficiently and packs soil around the seedling roots. It is desirable to have someone follow the machine and tamp around loosely packed seedlings.

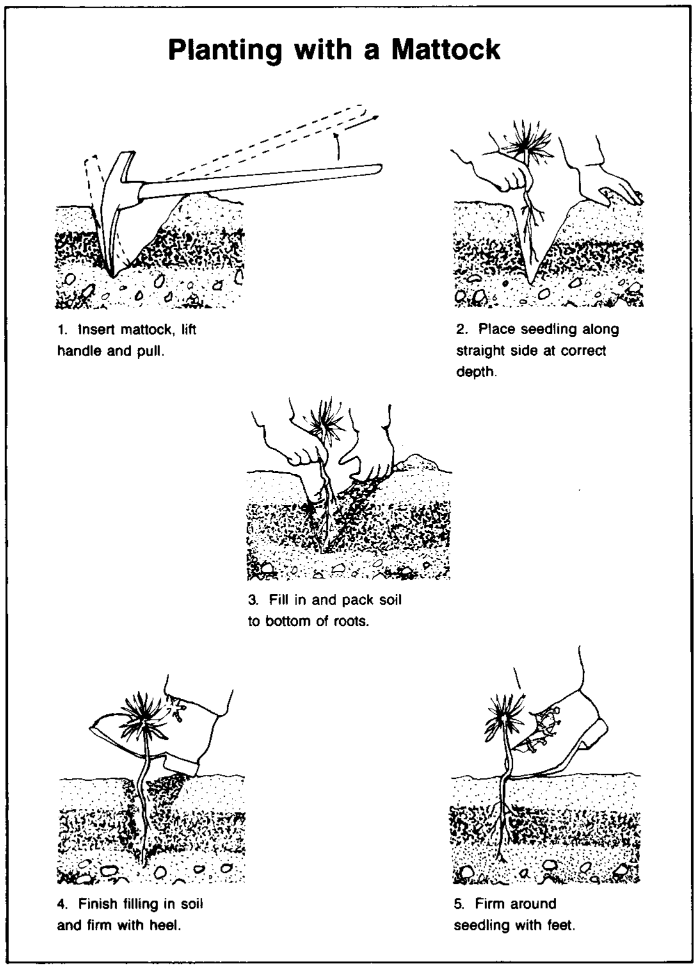


Figure 13. Planting tree and shrub seedlings with a mattock (redrawn with permission from John Wiley & Sons, Inc. and Alabama State Forester).

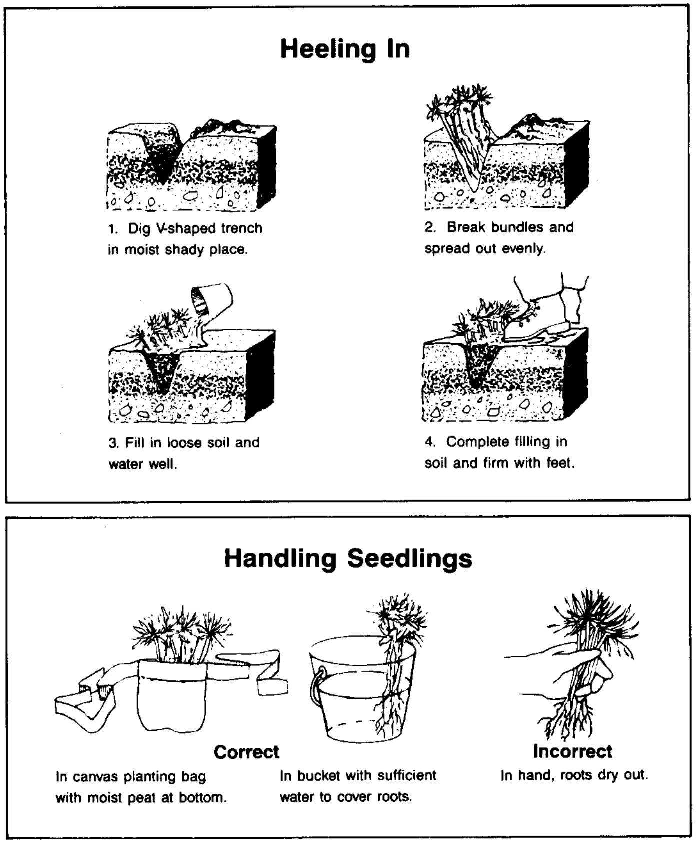


Figure 14. Methods of handling seedlings before planting (redrawn with permission from John Wiley & Sons, Inc. and Alabama State Forester).

The mechanized tube planter is a specially designed implement that automatically augers holes and plants 24-inch-long containerized seedlings. Competing vegetation is scalped from around the hole and soil is firmed around the planted seedling as part of the operation. The planter is expensive and the seedlings it plants are more costly to grow than seedlings of more conventional size.

Trees as large as 10 inches in diameter can be transplanted from the wild to mined areas with a tree spade. The root ball must contain enough of the tree's roots to enable it to survive and become reestablished at the new site. Transplanting with tree spades is costly and probably is warranted only for planting species that are otherwise difficult to establish, or to achieve immediate stocking or a landscaping effect with older and mature plants.

Front-end loaders with conventional buckets or with a specially designed bucket called a dryland sodder are used to transplant trees, shrubs, and pads of sod from their native location to the reclamation site. Woody species with shallow or spreading root systems are better adapted than tap-rooted species to this method of transplanting.

Species such as hybrid poplars and willows often are propagated from cuttings. A planting hole for cuttings can be made with the planting bar or mattock, or a pointed planting bar can be made from steel rod about three-quarters of an inch in diameter. The hole should be deep enough to place at least two-thirds of the cutting in the ground. In the East, cuttings about 10 inches long usually are planted, but longer ones may be needed in more arid areas. Cuttings should be planted before they break dormancy and the buds should point upward.

Figure 15. Mechanized seedling planter.

Direct Seeding

Direct seeding of trees and shrubs appears to be an attractive alternative to hand planting of seedlings, especially on steep slopes. However, direct seeding on surface mines has been successful with relatively few species; even with these, results have not been consistent. Direct seeding of woody species is advised only where there is a history of reasonable success. For example, direct seeding is the principle method of planting southern pines in Alabama and other Southern States. But in Central and Northern States, success with direct seeding of any species of pine has been inconsistent and the practice is considered risky. Black locust is easily established by direct seeding in the Appalachian and Midwestern regions. Direct seeding of black walnut and some oaks, particularly bur oak, has produced varied results in the Midwest; in a few planting trials, seeded walnut were more successful than planted seedlings. Treating seed with bird and rodent repellent can reduce pilferage of seed. Cold stratification (33° to 41°F) in a moist medium usually improves first-year germination of seeds of pine and some other species.

Broadcast seeding on a mechanically prepared or frost-heaved seedbed in late winter or early spring is a common method for direct seeding species with small seeds. A stand of more evenly spaced trees can be achieved by spot seeding. Row seeding machines can be used on minesoils that are relatively level and free of stones. Large seed, such as acorns and black walnut nuts, should be planted 1 to 3 inches deep at uniformly spaced spots. Where hand planted, two or three seed per spot are recommended to compensate for the nonviable seed, loss of seed, and mortality of young plants. A mechanical seeder capable of planting these large seeds has been developed in Kentucky.

Time of Planting

The best time for planting woody species is just before the period of the most reliable precipitation. Late winter through early spring normally is the best time in the East for planting woody species. Planting can begin when the ground is no longer frozen and as soon as seedlings can be obtained from the nursery. Depending on weather conditions, the beginning date for planting may vary by as much as 3 weeks from one year to another. Planting of nursery stock usually should be terminated by May 15 in northern regions and by April 15 in central to southern regions. Planting can be extended later into the spring at the higher elevations than at lower elevations.

Planting in late fall or early winter has been only partially successful, the successes occurring mainly on the more "ideal" planting sites. Seedlings planted in the fall are susceptible to frost heaving and the resultant drying of roots. Fall planting, where necessary or desirable for distributing job loads or because of labor shortages in the spring, should be restricted to minesoils least susceptible to frost heaving, such as those with moderate to dense ground cover and sandy or loose shaly loam soils.

Planting Patterns and Spacing

Several patterns can be chosen for planting trees and shrubs.

A *random mixture* implies that the species are intimately mixed and the seedlings planted with no designed or selected pattern for their placement. Random planting requires additional labor because it is necessary to mix the seedlings before giving them to the planting crews.

In *single row mixtures*, one species is planted per row. A different species is planted in an adjacent row. In *multiple row mixtures*, two or more adjacent rows are planted with the same species. Then, another set of two or more rows are planted with a different species. Rows usually run the full length of the area being planted.

In *block or group mixtures*, one species is planted in a block or group composed of several rows that are of some predetermined length. A different species is planted in an adjacent block of similar or other predetermined size. Randomly placing small blocks or groups of single species most nearly simulate the pattern of reproduction in a natural forest.

Where included in tree mixtures, nitrogen-fixing "nurse" trees and shrubs uniformly spaced throughout the planting probably provide the most benefit to adjacent crop trees. The composition of nurse trees in the mixture can determine their spacing arrangement. To make up 25 percent of the mixture, plant the nurse trees in every other space in alternate rows. To make up one-third of the mixture, plant every third row to nurse species. Spacing patterns can be designed where nurse trees make up 20 percent or less of the mixture, but randomly mixing them with the crop trees may be the easiest planting procedure.

The spacing of planted trees and shrubs varies with locality, purpose of the planting, species, and requirements of regulatory agencies. For commercial forestry (timber production), ideal spacing is wide enough to postpone the first thinning until merchantable products can be obtained, and close enough to ensure good form and development. As a rule, conifers are planted at a slightly wider spacing then hardwoods. Planting 800 to 1,000 trees per acre usually is recommended for conservation purposes and for development of a productive forest. Spacing at 6 by 7 feet (about 1,000 trees per acre) or 7 by 7 feet (about 900 per acre) frequently is recommended for mixed hardwood plantings. Spacing at 7 by 8 feet is recommended for conifers.

Christmas tree plantings usually are spaced 5 by 5 feet, or sometimes 6 by 6 feet. For hybrid poplars planted alone, an 8- by 8-foot spacing is recommended; but if planted in alternate rows with conifers, black locust, or black alder, a 7- by 7-foot spacing is advised. Closer spacings may be desired for screen plantings along roads, in block plantings of shrubs used for wildlife habitat, and on slopes where erosion control is a major concern.

The usual planting procedure is to space seedlings uniformly over an entire area. An alternate method that may improve stabilization and erosion control on slopes is to plant the seedlings close together (4 to 5 feet apart) in two to four closely spaced rows (5 to 6 feet apart) on the contour. The spacing of seedlings in one row alternates with the unplanted space in the adjacent rows. The distance between groups of rows may range from 20 to 40 feet. This spacing also provides a suitable planting pattern for wildlife habitat, especially when shrubs are used.

The following are the approximate number of trees planted per acre at various spacings:

5′ × 5′	= 1,740	6′ × 9′	= 905
6′ × 6′	= 1,200	7′ × 8′	= 780
6′ × 7′	= 1,035	8′ × 8′	= 680
6′ × 8′	= 905	8′ × 10′	= 545
7′ × 7′	= 890	10′ × 10′	= 435

Tree-Herbaceous Competition

Competition or incompatability between tree seedlings and herbaceous ground cover can influence the success of establishing trees. Woody seedlings planted in tall, dense vegetation can be shaded out. Competition with herbaceous vegetation for water, and possibly nutrients, also may lead to failure of woody plantings. Allelopathy —chemical competition between plants—is another factor to consider. Some herbs, especially grasses, release chemical compounds that are toxic to other plant species or to microbial populations such as mycorrhizal fungi that woody species depend on. These toxins may be released from live roots, live shoot material, or litter on or in the soil. The extent of the problem on minesoils is not well researched.

Where trees are planted in an established herbaccous cover, the competition between herbaceous and woody species can be avoided or reduced by planting the woody species in spots or strips where the cover has been controlled with herbicides, or where it has been removed by scalping with a fire plow or other implement.

Chances for successfully establishing trees concurrently with herbaceous cover can be increased by sowing the herbaceous species in strips that alternate with unseeded, or unfertilized, strips in which only trees are planted. The width of the seeded and fertilized strips can vary to facilitate the desired spacing of trees. With an 8 by 8-foot spacing, for example, 5-foot-wide seeded strips would alternate with 3-foot-wide unseeded strips, or, if seeded, not fertilized. Tree seedlings are planted 8 feet apart in the center of the unseeded strips. Ideally, the unseeded strips will remain free of herbaceous vegetation long enough to allow tree establishment, yet the cover in the seeded strips will provide adequate erosion control. For best control of erosion, strips should run on contour. This planting procedure will work best on areas where equipment such as seeding drills and drop-type fertilizer spreaders can be used for establishing strips that are uniform in width and spacing.

Availability of Planting Stock

Planting stock of woody species can be obtained from Federal, State, and private nurseries. Some State nurseries provide plants for in-state use only. Others sell surplus stock to customers outside their State. Generally, State nurseries provide stock that is of the quality and size suitable for planting mined lands. Many private nurseries also advertise bare-root seedlings and container stock in quantities and size suitable for planting mined lands. Private nurseries often are the only source of species not commonly used in reclamation and State-promoted reforestation programs.

Orders for woody species should be made at least 1 year in advance of planting. For some species, it may be necessary to notify nurseries even sooner because the selected species may not be raised in the quantities needed for reclamation planting or because more than 1 year is required to produce plants large enough for outplanting.

To ensure the hardiness of woody plants, purchase seedlings that have been propagated from plants growing in environmental conditions similar to those in the area to be planted. Research has shown that variations in the characteristics of parent trees due to climatic conditions may be carried on through their seed.

Mulching

A mulch is any material placed or left on or near the soil surface to protect it from erosion and to aid in the establishment of vegetation. This is in contrast to an amendment that is incorporated into the rooting zone of soil to improve vegetational growth and production. Some organic materials nominally incorporated into the soil may function as both mulch and amendment.

Reason for Mulching

Mulches cause the kinetic energy of raindrops to break and dissipate and thereby greatly reduce "splash" erosion wherein soil particles are dislodged from the surface and carried downslope by repeated dislodgement and in water flow. Mulches also slow the flow of runoff water over the surface. Each particle of mulch in contact with the surface may act as a tiny dam that interrupts and sometimes stops the flow of water. This causes soil particles to settle and allows water more time to infiltrate into the soil. Mulches impede the erosive forces of wind by physically sheltering soil particles and decreasing wind velocity at the soil surface.

Mulches aid in the establishment and growth of vegetation because they (1) reduce evaporation and conserve soil moisture (the upward movement of salts also may be slowed); (2) restrict air movement and allow higher relative humidity at the soil surface, reducing water diffusion from soil air into atmospheric air; (3) lessen the sealing over and crusting of the soil surface, thereby improving infiltration; (4) modify extremes in temperatures at the soil surface; (5) hold seed and small seedlings in place and enhance the microenvironment for seed germination; (6) sometimes introduce beneficial microorganisms into the soil; (7) provide an energy source for soil microbiota that contributes to soil aggregation and stabilization; and (8) lessen the occurrence of frost heaving of seedlings and young plants, a phenomenon prevalent in some soils and climates.

Mulches are most needed and especially beneficial under conditions of environmental stress such as limited precipitation and soil moisture, high temperature, and salty soils. These conditions typify many of the surface mines in the arid and semi-arid sections of the Western Coal Region. Potential for wind erosion also generally is more prevalent in this region than in the East.

Surface-mined lands in the humid Eastern Coal Region often have been seeded and vegetated successfully without the use of mulch. But even in these circumstances, vegetative cover usually is established more quickly and with less soil erosion where mulch is applied to new seedings. An example where mulch is especially beneficial, even in the humid Eastern United States, is on extremely acid spoils where a relatively shallow rooting zone (usually 6 inches or less) is created by the incorporation of lime. Mulch is important in conserving moisture in this shallow rooting zone and aids and hastens seed germination and seedling establishment.

Considerations for Mulch Selection

No one mulch material is ideal for all revegetation situations, nor do all materials provide exactly the same function and results. Several factors may need to be considered in choosing the mulch best suited to the revegetation objectives and characteristics of the area being mulched. These factors include (1) the proposed land use; (2) climate and weather characteristics such as intensity and frequency of precipitation, temperature, and wind velocity and frequency; (3) topography and soils; and (4) availability and cost of mulching materials.

A material containing seed of a variety of plant species may be acceptable for mulching areas planned for wildlife habitat, but undesirable for cropland. On exposed sites where high winds are common, mulches with heavy particles or those that can be anchored to the soil may be required. Similarly, materials that float easily would not be suitable for slopes where flow of water over the surface could be expected as a result of high intensity precipitation. Some materials may be relatively stable on soils left with a roughened surface, but would not stay in place on smoothly graded soils.

Light-colored mulches typically help lower temperatures at the soil surface. These are especially beneficial on dark soils where surface temperatures can be lethal to emerging seedling and small plants. Dark mulches applied in early spring may help warm soils sufficiently to cause early or premature germination of seeds. Where coincident with or followed immediately by a period of inadequate precipitation, the soil moisture may be depleted quickly and the emerging seedlings may die. Similarly, seedlings that emerge prematurely may be susceptible to a killing frost.

An excessive amount of organic mulch may cause a water shortage to seedlings by intercepting and holding some or most of the precipitation in the mulch layer and allowing it to evaporate. A thick layer of mulch also may attract small rodents that eat seed and emerging seedlings. A remote possibility with some mulching materials is a wicking action whereby moisture is drawn from the soil in dry periods.

Organic mulches, especially those with a high carbon to nitrogen ratio due to their high cellulose content, can cause nitrogen deficiency to plants because the microorganisms that break down the organic matter are more efficient than plants in utilizing inorganic nitrogen in the soil. However, this problem is more severe where the organic materials are incorporated into the soil than where they are placed as a mulch on the surface. Additional nitrogen fertilizer can be applied to compensate for the microbial tie-up of nitrogen.

Perhaps most importantly, the choice of mulch for a specific reclamation job will depend on the availability and cost of material, transportation costs, and ease and cost of application. Some residue materials such as bark, though often obtainable at little or no cost, are costly to handle and transport and may require costly or specialized equipment for application. To be economical, supplies of such material should be available in sufficient quantities on or near the reclamation site. Sometimes an alternative mulching material is available but not accepted by a potential user because of personal bias or lack of knowledge and uncertainty of its value. Wood chips, for example, are believed erroneously by some to be acid producing and toxic to vegetation.

Mulching Materials

The mulching materials most used in mined-land reclamation are organic products and residues from agriculture and wood-processing industries. Some of these materials are relatively inexpensive; the major cost in their use is transporting them to the reclamation site.

Agricultural Residues

Raw residues from agriculture, especially straw of cereal grains, such as wheat, oats, and barley, and hay, that consists mainly of grass, are some of the best and most popular mulches. Straw is sometimes preferred because it does not decay as rapidly and, in some areas, costs less than hay. Seed not threshed from grain straw can produce vegetation that may be considered desirable where it complements the primary goal of a quick vegetative cover or undesirable where it competes with and inhibits the establishment of desired seeded species. Mulching with hay may add seed of desired reclamation species to the site, but in other situations, it may introduce unwanted and undesirable species that will interfere with revegetation and land-use objectives.

Straw and some types of hay are effective in reducing the temperature of the soil surface because of their light color and reflective qualities. These materials applied at 1 ton per acre can reduce soil temperature by 10° to 15°F. This may be a potential disadvantage in the spring because warming of the soil, seed germination, and early crop growth could be delayed. Recommended application rate for straw and hay mulches are 1 ½ to 2 tons per acre. Uniform application is important. Resistance of the mulch materials to movement by wind and water is increased by tacking them down with asphalt emulsion or other chemical tacking material; by pressing them partially into the soil with a specially designed crimper, disk harrow, or sheep's-foot roller; or by placing netting firmly over the mulch and anchoring it securely to the ground. Other agricultural residues that can be used for mulch include peanut hulls; crushed corn cobs; shredded corn stalks or fodder; rice straw; and bagasse; a residue from sugar cane mills. These and similar crop residues are available and used mostly in local areas and seldom are important on a regional basis.

Figure 16. Power mulcher spreading straw.

Several types of mechanical mulchers are available for spreading straw, hay, and similar materials. Mulch blowers or power mulchers that handle standard-size square bales are made by several companies and are the most common (Figure 16). The bales are fed into the mulchers, separated by beaters, and blown out through a discharge spout. Some mulchers are equipped to spray a chemical tack on the mulch as it leaves the discharge spout. Mulch can be blown a maximum distance of 80 feet in ideal wind conditions and it can be applied both up and down slope. About 40 acres can be mulched in an 8-hour day. Four people are required to operate a power mulcher efficiently. A fifth person is needed where a crimper or disk is used to anchor the mulch to the soil.

Other machines for spreading hay and straw are a modified manure spreader, a modified stack processor, and a modified rotary tub grinder. The advantage of the modified stack processor and tub grinder is that they can handle large round bales of hay or straw (1,200 to 1,500 pounds). The rotary tub grinder also handles small standard-size bales and loose hay and straw. It spreads bark, wood chips, composted garbage, and similar products and is not damaged easily by foreign objects. Mulch can be blown 60 to 70 feet in ideal spreading conditions on level to gently rolling terrain (Figure 17). From 20 to 40 acres can be mulched in an 8-hour day with a 2-person crew.

Straw and hay mulch can be applied by hand on small areas and slopes that are beyond reach of a mulch blower.

Animal manures can function as mulches, but often are incorporated into the soil because they are a source of plant nutrients. Where they are left on the surface, much of the N content may be lost through volatilization of ammonia. About 10 tons per acre is a recommended application rate for providing protection against splash erosion by raindrop impact. A manure spreader can be used to spread these materials (Figure 18).

Wood Residues

Materials such as bark, wood chips, and sawdust have been used as mulch in some areas. Technically, wood chips are not a residue where they have been processed primarily for other uses such as paper making. Chips processed from whole trees that otherwise would be wasted (burned or buried) on the mine site can be considered wood residue.

Raw or processed hardwood bark is an excellent mulching material for erosion control, for conserving moisture, and for aiding in the establishment of vegetation. The weight (density) of hardwood bark and the nature of its fibers that tend to interlock enable it to stay in place without tacking material, even on slopes. Bark of softwoods and wood chips are less dense and will float in runoff water more easily. Sawdust and shavings are least desirable for mulch because they blow and wash away easily. Wood chips, sawdust, and shavings have a higher cellulose content than bark; thus, nitrogen requirements for the microorganisms that decompose them is potentially greater than for bark. However, the concern that wood residues contain toxic components harmful to vegetation has been overplayed. Adverse effects on plants have been documented for bark or chips of only a few minor hardwood and conifer species.

Figure 17. Modified rotary tub grinder spreading mulch on snow to show spreading pattern.

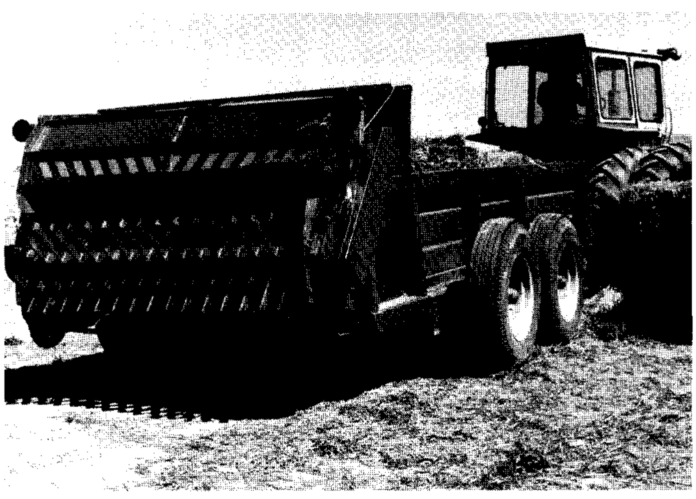


Figure 18. A modified manure spreader that spreads straw mulch.

Bark and woodchips will not decay as rapidly and thus last longer than hay and straw. Usually, few or no weed seeds will be introduced with these materials, but some, especially bark, could be a source for introducing beneficial endomycorrhizal (VAM) fungi into the soil. Where bark, wood chips, straw, and hay mulches have been tested side by side, the establishment of seeded legumes was more rapid and dense in bark and wood chips.

Recommended mulching rates for bark and wood chips are 40 to 60 cubic yards per acre. This provides a depth of about 0.3 to 0.5 inch. The higher rate is suggested for all slopes greater than 2:1, south- and west-facing slopes, and for overwinter protection of a site. Rates up to 100 cubic yards per acre can be used without retarding the emergence of most seeded species. Bark or wood chips applied 3 to 4 inches deep around planted tree and shrub seedlings would prevent the emergence of most seeded species and thereby prevent immediate competition from seeded herbaceous vegetation.

Application rates for bark and wood chips are often defined in volume measure rather than weight because the moisture content of these materials stored outdoors and the density of different woods can vary considerably. A crude conversion of volume to weight for field use is: 4 cubic yards of wood chips or 3 cubic yards of bark weigh about 1 ton.

Salvaging and converting woody vegetation that is removed and usually wasted ahead of mining is a potential source of wood chips. In most forested regions, only a part of the total woody vegetation removed from the mine would be needed for mulch. The primary drawback to processing whole-tree chips on site is the high cost of specialized equipment for hauling and chipping logs and additional labor. The establishment of a business venture to provide this service on several mines may be a way to circumvent the high cost to an individual mine.

Although not a wood residue, leaves are a residue of woody plants and present a disposal problem in some urban communities. Leaves are collected and baled in some communities and may be available for mulching nearby mined areas. The major problem is that leaves are most available in the season when mulch is least needed. Leaves need to be slightly incorporated into the soil or otherwise tacked to hold them in place. Two to four tons per acre are needed to be effective.

Shredded bark, wood chips, corn cobs, sawdust, composted municipal wastes, and similar products used for mulch or as organic amendments can be applied most easily with an Estes Spreader, a blower/thrower mechanism that is attached to either a conventional or modified hopper of a lime-spreading truck (Figure 19). This spreader is most advantageous for spreading mulches on steep slopes, either up or down, but also spreads efficiently on level areas. Mulches such as bark and wood chips can be thrown about 75 feet up a 2:1 slope and as much as 125 feet horizontally. In addition to the thrower mechanism, the spinners that are standard equipment on spreader trucks can be used to apply mulch on level or gently sloping areas. The thrower and spinners can be used together or independently. To avoid damage to the thrower mechanism, materials that contain large particles, such as pieces of boards, stones, and other foreign objects, must be screened or ground before loading into the spreader. The Estes Spreader also is used for applying lime and fertilizer.

The modified tub-grinder mulcher described earlier spreads bark, wood chips, and most any other organic material. Bark, wood chips, baled leaves, and materials of similar form can be spread on level to gently sloping areas with a standard farm manure spreader (Figure 14). Spreading these materials by hand is difficult and tedious even on small areas.

Figure 19. The Estes Spreader is effective for applying bark, wood chips, lime, fertilizer, and other materials on both level and steeply sloping areas.

Wood Fiber and Cellulose (Hydromulches)

Processed wood fibers prepared from selected woods and reprocessed waste paper, often referred to as wood cellulose, are popular mulching materials that are mixed with water and applied with a hydroseeder or hydromulcher (Figure 9). The fibers in these materials are short and their durability as a mulch is short-lived. They also are less effective than straw or hay. Most of the commercially available fiber and cellulose mulches are colored with dye so that they are plainly visible when applied on the ground; this aids the operator in obtaining uniform coverage. These materials are sold in bales that are easily handled and conveniently stored.

Common application rates of the hydromulches are 1,500 pounds per acre or less. The 1,500-pound rate provides only minimal coverage and rates of 2,000 to 3,000 pounds per acre are needed to provide a true mulch effect. However, the higher rates greatly increase the cost of application because the capacity of the hydromulcher allows for treatment of only a relatively small area with each load of material. For example, a hydromulcher with a 3,000-gallon tank can hold 1,500 pounds of fiber mulch—the minimum needed for 1 acre. On average, up to 6 loads, or treatment for 6 acres, can be applied in an 8-hour day. By contrast, up to 40 acres can be mulched with straw in an 8-hour day with a power mulcher.

Sometimes these mulches are applied in a slurry mixed with seed and fertilizer. Such a mixture may allow some of the seed to be perched above the soil surface in a web of mulch, exposing the germinating seed and tender seedlings to drying and extremes of temperature. The probability of this effect causing seedling mortality is greatest in areas of low rainfall, but it can occur even in humid areas during prolonged dry periods. A preferred procedure in these circumstances is to apply seed and fertilizer first and the mulch in a separate application.

The primary advantage of the hydraulic method of mulching is that mulch can be applied to areas, such as the far end of steep slopes, that cannot be reached by other methods. The spreading distance by the larger hydroseeders is as much as 200 feet. For treating areas beyond that distance, a hose attachment is available. One drawback of hydromulching, especially on some western mine sites, is lack of sufficient water. In some situations, water is available in the vicinity but requires a long haul from the source to the mine.

Other Mulching Materials

Mats and netting made from wood fibers and other assorted organic and synthetic materials are effective for controlling erosion in specialized uses. The cost of these materials is prohibitive for general use in surface-mine revegetation. Sites for their use generally are those considered critical for esthetic purposes or erosion control and should be prepared under controlled or engineered standards. For example, netting may be useful in an emergency spillway on an earthen dam that requires quick, positive protection while a complete vegetative cover is being established.

A layer of crushed rock or gravel provides an effective mulch; however, the cost of material and application may be excessive for wide-scale use. A rock mulch is particularly useful in arid regions where complete vegetative cover is not usually present or possible to attain.

Mulches Grown in Place

Quick-developing annual grasses can be sown for growing mulch in place. The grass species should be compatible for the season; for example, winter annuals, such as wheat and rye, are sown in late summer to fall and summer annuals, such as sudangrass, sorghums, pearl millet, or Japanese millet, are used for late-spring through early-summer seedings. For growing mulch in place, the seeding rate of the annuals should be increased over the rate normally used in mixtures, and soil amendments should be applied as needed to promote plant growth.

Perennial species can be established subsequently by seeding or planting them directly into the annual crop residue (in-place mulch). Where mulch is produced by summer annuals, planting of perennials usually is done the following spring. But spring planting of perennials into a winter annual crop may first require the use of a herbicide to kill the annual-plant competition. This would be most essential for establishing woody species. Seeding perennial herbs could wait until late summer, after the winter annual vegetation has matured.

A practice used on arid land is to either grow a sterile variety of cover crop or cut it before it produces seed. Either way, there are few viable seed when the reclamation species are sown into the standing stubble. This is especially appropriate where fall is the preferred seeding time. By establishing the temporary cover crop the previous fall, or in spring or early summer, the minesoil is stabilized until the fall seeding of permanent reclamation species is made.

Soil Stabilizers

Soil stabilizers are organic and inorganic chemical products that are applied in water solutions to the soil surface to temporarily stabilize the soil against wind and water erosion and to retard the evaporation of soil moisture. In the humid eastern United States, the effectiveness of chemical stabilizers is relatively short lived compared to most mulches. Stabilizers are expected mainly to control erosion only until vegetative cover is sufficiently established to protect the site.

Soil stabilizers often are classed by their basic formulas, e.g., polyvinyl acetates, acrylic copolymers, elastometric emulsions, and natural vegetable gums. There are many of these products on the market and similar products may differ from each other only because of additives mixed with the basic formula. The additives affect curing time, crust durability, and moisture infiltration rates. The effectiveness of these products is further influenced by dilution rate with water, soil properties, weather conditions, and amendments, such as fertilizer added to the solution to aid vegetation establishment.

Some of the stabilizers form a thin film on the surface that provides temporary protection against soil movement. But most of these products infiltrate as much as 1 inch into the soil and bind the soil particles together to form a crust that resists erosion. High soil moisture limits the depth of infiltration; therefore, stabilizers may be more effective on soils with moisture content below field capacity. Also, warm dry weather is more conducive than cool damp weather to proper curing of the stabilizers. Tough crusts may form that physically restrict seedling emergence of some plant species, especially grasses and forbs with tiny seeds.

Table 8. Common application rates of mulch per acre.

Mulch	Intended use		
	Seed Cover	*Erosion Control*	*Plant Mulch*
Straw (tons)	1.5–2	3	4
Hay (tons)	2	3	4
Manure (tons)	10–15	30–40	40–60
Hardwood bark (yd^3)	45	240	480
Softwood bark (yd^3)	45	240	480
Hardwood chips (yd^3)	50	268	536
Softwood chips (yd^3)	50	268	536
Leaves (tons)	3	4	5
Wood-cellulose fiber (lb)	1,500	3,000	—

Many of the stabilizer products can be used as chemical tacks to hold straw, hay, and other lightweight mulches in place. The stabilizers also are used in combination with wood-fiber and wood-cellulose mulches. In fact, the wood fiber-stabilizer combinations are used more frequently than stabilizers alone. Presumably, site protection obtained with low rates of the combined materials is comparable to that obtained with high rates of either product used along. A combination used in some Eastern States is 50 gallons per acre of stabilizer mixed with a minimum of 500 pounds per acre of wood fiber or wood cellulose.

Because they can be applied with a hydroseeder, soil stabilizers have an advantage over most mulches for treating long steep slopes and other hard-to-reach places. However, for general application, mulches are more widely used and provide several advantages over soil stabilizers. Soil stabilizers cost more and require more precise preparation and procedural control than mulches. Also, the use of soil stabilizers is a relatively recent development and there is insufficient knowledge about the comparative value of different products and about the most effective application rate for specific soils, sites, and weather conditions. That many products sold as soil stabilizers have come and gone from the market may be evidence of the uncertainly of their value for reclaiming disturbed lands.

It is not possible here to list all of the soil stabilizer products currently available, or to make a comparative rating of their value. For those interested in using soil stabilizers, advice should be sought from research reports on their use and from reclamation companies, highway departments, construction companies, and conservation agencies that may have used them.

Application Rates

The selection of the optimum rate and depth of a mulch is influenced by intended use and the effectiveness of the mulch in modifying environmental factors associated with the site conditions. Soil and seed protection, erosion control, and growth enhancement are the primary purposes for use of mulch and are the most logical components on which to base application rates (Table 8).

An important consideration in the efficient use of mulch is that of mulch depth in relation to application rate. Also, the rate and depth of application varies due to the type of material and particle size. For example, 135 cubic yards of bark minichips will cover 1 acre 1 inch deep; whereas it takes 160 cubic yards of chunk bark for the same coverage. Coverage with straw at 1-1/2 tons per acre provides about a 1-inch layer.

Coarse and more bulky material can be applied in greater depths than those of small materials that will compact. The selected material should be sufficiently loose and open for free circulation of air to favor development of vegetation.

Considerable care should be taken to ensure that mulch material is spread evenly over the area. A partially covered surface is less efficient in protecting the soil surface from falling rain and controlling soil washing. As the proportion of cover increases, runoff decreases. The effectiveness of mulch in stabilizing the soil surface is a function of coverage and durability.

Usually, the minimum amount of mulch coverage needed for surface protection is 75 percent. It has been shown that, when compared to a bare site, a mulch coverage of even 50 percent reduced the erosion rate by 35 to 40 percent for a wide range of steepness and length of slopes.

POSTMINING LAND USES

Agriculture

Agriculture often is equated with the highest and best use for reclaimed surface-mined land. This seems to be justified primarily on economics, especially on nonprime farmland areas where costs to revegetate usually are lower and economic returns potentially quicker and greater for such agricultural uses as pasture than for such uses as forestry and wildlife habitat. Agricultural uses obviously are appropriate and suited on many reclaimed mines, especially on areas identified as prime farmland. Agricultural uses, especially pasture, also are being proposed in mining areas where agriculture historically has not been an important part of the economy and where absentee land ownership is commonplace. In such situations, the immediate economic advantage of establishing vegetation for pasture rather than forestry, for example, may not justify the conversion of premining forest land to postmining pasture in view of the likelihood of little or no future management of the reclaimed area.

Change from premining nonagricultural land uses to postmining agricultural uses is a trend taking place in some agricultural regions. Here an important consideration is the loss of nonagricultural plant communities that provide the primary sources of wildlife habitat, woodland, recreation, and landscape diversity in predominantly agricultural environments.

Row Crops and Small Grains

Where the postmining land use is to be agricultural, it is important that the type of use and crop selection be compatible with the characteristics of the soil and overburden materials. The production of row crops is most often associated with and most likely to be successful on reconstructed prime farmland that can be tilled, managed, and harvested in the same way as unmined farmland. Such crops as corn, sorghum, and soybeans are most likely to be confined to such areas. Grain crops, such as wheat, oats, and barley, can be produced on some nonprime farmland areas, even where little or no topsoil is replaced. However, in some such cases, continued cropping may not be feasible because of minesoil conditions, such as stoniness, that interfere with tillage and harvest operations.

Soil erosion is a potential problem on cultivated cropland. The use of annual cover crops, especially for overwinter protection, and incorporation of organic materials, such as barnyard manure and crop residues, will help stabilize the soil and reduce erosion. It is especially important that soil conservation practices applicable to normal agricultural operations be used on minesoils reclaimed for cropland uses.

Pasture and Hayland

Pasture is a common and widespread postmining land use, particularly in the eastern half of the United States. Some reclaimed mines also are suitable for producing hay, particularly areas free of steep slopes, stone, and other obstacles that would interfere with the cultivation and harvest of the hay crop. Plant species used for pasture and hay often are the same as those used for cover and erosion control. However, because of differences in palatability and nutritive value to livestock, some species are preferred over others. For example, KY-31 tall fescue is used widely in the East for erosion control. It is also used widely for pasture and hay, but other grasses, such as orchardgrass, timothy, and smooth brome, are considered to be more palatable and nutritious as livestock forage. Legumes, such as sericea lespedeza and flatpea, are excellent cover and erosion control species, but are less desirable than alfalfa and some of the clovers for forage.

Nearly all of the grass and legume species used in improved pasture and haylands throughout the United States are introduced (not native), though they are naturalized. Productivity of these pasture and haylands usually is maintained by periodic application of fertilizer and, in the Eastern U.S., lime. In some situations where soils are naturally fertile and good land management is practiced, productivity of legumes alone and grass-legume mixtures may persist for several years without fertilizer. Productivity of mixtures is most likely to persist where the legume component is maintained in about equal proportion with the grass.

Annual and short-lived perennial species are sometimes used for hay or temporary pasture in agricultural situations. Such use may be feasible on newly revegetated mined land only in management situations where these types of species are sown in association with perennial forage species and harvesting or grazing them would aid the development of the perennials. However, in most situations, early or premature grazing by livestock or harvesting of any new or recent seeding may be injurious to the successful establishment of vegetational cover.

Native species for postmining pasture and hayland use seldom are used in most mining states east of the 100th meridian. Exceptions are found primarily in the Western Interior Coal Region and the coal mining areas of eastern Texas, where several grass and forb species native to the Tall and Mid-Grass Prairie types have been established successfully on mined land. However, restoring native prairie on mined land is virtually impossible because some 200 to 300 species of grasses, forbs, half-shrubs, and shrubs are known components of the Tall Grass Prairie. In practice, only a small percentage of these species can be reestablished in artificial plantings.

There is potential for greater use of native species, especially warm-season grasses, for pasture in all of the Eastern States. In experimental plantings on minesoils, forage production from these grasses greatly exceeded production of introduced cool-season species during drouthy summers. One deterrent to the use of native grass species in the East is that traditionally they have not been used for pasture and potential users lack knowledge about their management and value for summer forage. The seeding of native species for forage is associated primarily with range use in the coal mining areas west of the 100th meridian.

Rangeland

Rangeland or range is the major land use in most of the coal mining regions in the arid and semi-arid western half of the United States. Range usually denotes land producing native vegetation (forage) for animal (livestock and wildlife) consumption. A major concern and consideration in revegetating mined rangeland is the reestablishment of plant species native to the region and affected sites. One important reason for this is that native species are adapted to the environmental conditions of the area and sites where they naturally grow and are more likely to persist and develop permanent plant communities than introduced species. Some introduced species also are adapted to rangeland conditions and sites and are useful for providing ground cover and forage for livestock. Some introduced species are adapted to an even greater range of sites and environmental conditions than most native species, and these are an important part of the grazing management program on many ranches. Pastures of some adapted introduced species, such as crested wheatgrass, can be grazed in periods preceding and following normal periods for grazing native range.

Mixtures of adapted grasses, forbs, and shrubs are desirable for revegetating mined areas for range because they offer greater potential for establishing species adapted to differences in site conditions. In some cases, there is opportunity to plant species that will enhance the premining range condition and productivity. On some sites, unadapted introduced species, usually annuals, can be planted either before or with permanent species to temporarily stabilize the site and aid in the establishment of permanent species. But on other sites, especially where moisture is limited during the establishment period or where soils are low in fertility, the use of such nurse or companion species will delay or prevent the establishment of the planted permanent species. In these cases, seeding and planting only adapted species capable of plant colonization usually will be more successful.

Forestry

Forestry is a logical land use for many areas currently being mined, as well as for many abandoned or orphan mine sites. However, reforestation efforts have been minimal in recent years due to changing economic, political, legal, and social policies and pressures. Previously, the planting of trees often was considered an expeditious way to revegetate mined lands in the Eastern United States. Recent evaluations of 25- to 50-year-old forest plantings on mined sites throughout the Eastern States show that, on many of the sites, forest ecosystems are being reestablished from a combination of planted and naturally established vegetation. Some of the trees now are approaching or have reached marketable size, and such species as black walnut show promise for producing a favorable economic return.

Factors to consider in selecting tree species for reclamation include the forest management objective, species preferences in current markets, predicted preferences in future markets, the proposed level of management, and site and minesoil characteristics. The forestry objective can range from short-term crops, such as pulpwood, to long-term crops for timber production. Levels of management can be intensive, requiring regular care and treatment, or extensive, requiring little care or treatment. Obviously, markets for the harvested crop need to be within a hauling distance that is economical.

The best results with tree species can be expected where they are matched with site and minesoil quality. In the East, preferred sites for planting high-value hardwoods, such as black walnut, yellow-poplar, and sugar maple, have slightly acid to neutral loam and silt loam minesoils that are well drained but not drouthy. Conversely, many of the pine species are a better choice for sandy acid soils on warm (south-facing), moderately drouthy sites. However, attempting to match species to soil series that were present before mining may not be a productive effort. In the past, tree growth sometimes was better on spoil banks of mixed overburden materials than on nearby unmined native soils.

Pulpwood Production

Revegetating mined land for pulpwood production can involve either intensive or extensive management. Intensive management usually entails the planting of one fast-growing pulp species, such as shortleaf, loblolly, or longleaf pine; European alder; hybrid poplars; cottonwood; sycamore; or bigtooth aspen. Management practices may include periodic inspections for detection and control of insects and diseases, thinning, control of competing vegetation, and fertilization. With hybrid poplars and some of the other hardwoods, two or more rotations of pulp may be obtained from sprouts that originate after the first harvest.

Extensive management for pulpwood can be accomplished with pure or mixed planting. Trees cut for pulpwood may consist mainly of those removed when thinning stands designated for timber production or when creating openings for wildlife habitat. Only selected trees would be left uncut to develop into veneer or sawlogs.

Timber Products

This management objective implies a long-term commitment. The overall level of management is extensive but it can become intensive periodically when trees would benefit from thinning, pruning, and other cultural practices. Access for periodic inspection, cultural treatments, and fire protection is desirable. Due to the long timespan until timber harvest, interim benefits, such as wildlife habitat and nondestructive recreational uses, also can be considered.

For some timber production programs, especially with conifers, planting only one or two tree species may be desired. With hardwoods, mixtures of several species usually are preferred. Herbaceous and shrubby species can be included to provide initial site protection and to add vegetational variety for esthetic values and for the enhancement of wildlife habitat as an interim land use. The number and arrangement of shrubs may vary for different forestry management objectives, but shrubs (and trees planted primarily for wildlife use) should be limited, probably to 25 percent or less of the total planting, where timber production is the planned postmining land use. For the benefit of wildlife, planting shrubs in small blocks or bands rather than interplanting uniformly throughout the plantation is recommended.

Trees can be planted either in pure stands of one species or in mixtures of two or more. In general, stands of one species are easier to plant, manage, and harvest; but they are more susceptible than mixed plantings to insect and disease epidemics, and they lack diversity for visual quality and wildlife habitat. Mixed plantings improve the possibilities for natural regeneration and diversity, and usually occupy the site more fully than pure plantings.

Examples of several hardwood mixtures for timber production are shown in the chapter on Revegetating Coal Surface-Mined Lands in the Eastern Coal Regions. Obviously, many combinations of species are possible, and the choice of species may be influenced by several factors. For a given locality, consult appropriate natural resource agencies or services and State revegetation and forestry guides for additional advice on forestry procedures and species selection.

Wildlife

The basic components of habitat for wildlife are food, cover, water, home range, and interspersion. All are essential for survival. Food provided by a variety of plants must be available during all seasons and within range of protective cover. Different types of plant cover are required for different purposes, such as brooding and nesting, escape, and shelter. Some species of wildlife require open water; others obtain moisture from succulent plants, dew, or their own metabolic processes. The home range of a species is the size of its habitat or living area. The required size varies for different species. Interspersion is the arrangement of food, cover, and water within the living area of a species. Food and cover that otherwise meet the needs of a species may be of little value where they are not interspersed properly.

Habitat for wildlife can be developed either as the primary land use or in association with other land uses. However, it should not be assumed that every revegetation effort will automatically develop or improve wildlife habitat. Nearly every vegetational community will in some degree contribute to habitat, but the best habitat is developed by planning and providing for the needs of the desired wildlife species. In revegetating surface-mined areas, the maximum benefit for wildlife usually is obtained by establishing vegetational communities that are not presently available or that are in short supply in the vicinity. In a region that is predominantly deciduous forest, establishing communities of coniferous trees will provide greater diversity of food and cover than planting mixed hardwoods. Establishing shrub communities in forested and agricultural area where they often are lacking is especially beneficial to wildlife.

Each species of wildlife has different habitat requirements, so the vegetation established for different land uses will affect the diversity and productivity of wildlife populations. Bird populations in the East are most diverse and productive in a mixed hardwood forest. Different species of birds are attracted to and inhabit open grasslands; others prefer edges between forest and grassland that are partially vegetated with shrubs and small trees. Thus, even in a forested region, the overall diversity of bird species is increased by developing shrub and grassland vegetational types on surface-mined areas. Similarly, planting tree and shrub communities in grassland and agricultural regions increases the diversity of birds and mammals.

Habitat can be developed on mined land to favor one or two species, several species, or wildlife in general. But newly revegetated surface mines cannot be expected to provide habitat for all resident species of wildlife. Squirrels, for example, inhabit forests in advanced stages of succession. Ruffed grouse and wild turkey may derive benefit only from those newly revegetated sites that are adjacent to or interspersed with natural undisturbed forest or woodland. For bobwhite quail, cottontail rabbit, white-tailed deer, and other species, how little or how much of the habitat requirement is derived from the early stages of revegetation depends on the size of the area; type, age, and interspersion of planted vegetation; and the type and interspersion of land uses in the surrounding unmined areas. Habitat requirements should be determined before attempting to establish habitat for particular species of wildlife.

Woody Plants

Trees and shrubs are important components of wildlife habitat. In fact, development of wildlife habitat is a major reason for planting shrubs on reclaimed surface mines (Figure 20). For wildlife plantings, shrubs and trees usually are planted in rows, clumps, or blocks of a single

Figure 20. An informal planting of bicolor lespedeza that provides cover and food for wildlife.

species. Adjacent rows of different shrub or tree species can be planted to develop a "teepee" effect; that is, the tallest species are planted in the center of a strip or block and shorter species are planted in the outer rows.

Many woody plants provide both food and cover, but the relative importance of these values varies with different species of wildlife. Time of fruit or seed maturity and the duration of fruit or seed retention on the plant differ among tree and shrub species. Planting several species that differ in maturity and retention of fruit extends the period that food is available to wildlife.

The benefits of woody plants to wildlife do not occur as quickly after planting as with some herbaceous plants. For most woody species, 3 or more years of growth are required before they contribute effective amounts of cover and food to wildlife habitat. Some tree species, for example, some of the oaks, may require many years before they contribute mast to the habitat. Ideally, wildlife plantings that include a variety of woody plants will provide food for relatively long periods.

Planting Patterns

Diversity is the basic principle in developing habitat for wildlife. Planting patterns that provide variety and diversity in types and arrangement of vegetation are the most beneficial when all species of wildlife are considered as a group. For example, planting trees and shrubs in rows, strips, clumps, and blocks in and around open areas seeded to herbs creates a desirable interspersion of food and cover types and provides for better distribution of wildlife (Figure 21).

A suggested pattern for expansive sites would include grass-legume mixtures in strips 100 to 150 feet wide alternating with shrubs and trees in strips 30 to 50 feet wide. In some strips of woody plant, the inner rows should be trees and the outer rows shrubs. Clumps of fruit-producing trees also can be placed randomly throughout the open areas. Where an area is less than 150 feet wide, one to three rows of woody vegetation through the middle, or scattered clumps of woody plants, may create sufficient diversity in habitat. Open areas of at least 1/2 acre but no more than 5 acres seeded to grasses and legumes are recommended.

Figure 21. Interspersion of trees, shrubs, herbs, water, and landform provides habitat diversity that is essential for wildlife.

Wildlife habitat can be incorporated with other land uses chosen for the reclaimed mine. Single rows of dense shrubs between small pastures and crop fields can provide escape cover, shelter, and variety in food for game birds and small mammals. Extensive tracts revegetated for pasture, hay, or range can be diversified with occasional strips (up to 20 feet wide) of shrubs that produce fruit and cover. Similar plantings also can serve as woodland-field borders at the edge of pastures or cropland. Several rows of conifers and shrubs or small, fruit-producing trees planted at right angles to the direction of the prevailing winds can provide windbreaks for cropland or pasture while improving nesting, escape, and winter cover for game birds.

The boundaries or edges of plantings need not be uniform or exacting. Ragged, irregular edges increase the value of a planting to wildlife, and they can add esthetic interest to a site.

Mixed forest plantations provide good habitat for most species of wildlife that naturally inhabit forest land. Establishing blocks of conifers, up to 1 acre in size, within larger plantations of mixed hardwoods increases the variety of available food and cover types while providing potential wood products. Blocks of hardwoods separated from the conifers by grass-legume strips will provide more edge and open areas. Food patches of 1/8 to 1/2 acre, seeded to species such as partridge pea, soybean, wheat, white clover, or orchardgrass, will benefit some species of wildlife in a forest area. One food patch in about 40 acres is suggested. Prescribed harvesting of pulpwood and timber also may create diversity in wildlife habitat.

Vegetation, especially forest vegetation, changes with time. In turn, the quality and quantity of food and cover available for wildlife will be altered as the forest canopy closes in. To counteract this natural process of change, maintenance procedures are necessary. Open areas that become overgrown with woody plants may require cutting, discing, or controlled burning and reseeding to extend the longevity of the desired type of habitat.

The preceding discussion focuses on planting patterns for habitat for wildlife in general. Obviously, where habitat is desired primarily for one or two species of wildlife, variations in planting patterns must be provided that are most beneficial to those species. Additional recommendations on habitat requirements, management of the wildlife, and maintenance of habitat are available from professional biologists and other reference sources.

Horticulture

Developing mined land for horticultural purposes requires intensive management of both the soil and plants under cultivation. For the purposes of this handbook, the definition of horticulture is limited to the care and growing of woody species. To avoid confusion with forestry as a land use, horticulture as used herein refers to the culture of woody plants requiring some type of treatment at least once a year.

Within these limits, horticultural applications to mined lands include Christmas tree production, fruit orchards, nut orchards, vineyards, and berry production.

As with all land-use options, site protection is of primary importance. An herbaceous cover must be established as quickly as possible to prevent erosion. As soon as some degree of stability is achieved, the desired woody species can be planted.

Christmas Tree Production

Planting and management for Christmas trees is a moderately intensive practice. Species selected should be marketable in the region. Scotch pine, for example, is popular in the Eastern States and can be grown in all but the southernmost coal-producing areas. Other pines used for Christmas trees are red, eastern white, Austrian, ponderosa, and jack. Norway and white spruce, Fraser fir, and Douglas-fir also are used, but generally do not reach marketable size as quickly as pine. Pure plantings of a proven species usually are recommended, but mixed plantings of two or three species may reduce the risk of loss from insects and disease or from a change in market demand. Low-growing herbaceous species are recommended as a ground cover. Mowing and the use of herbicides may be needed to reduce competition from herbaceous plants.

Management requires a road system for maintenance, harvest, and fire protection. Fencing may be needed to protect the plantings from livestock, theft, and vandalism. Care of Christmas trees also includes shearing to shape trees for market; application of fertilizer; and protection from insects, disease, and fire. Specific information on Christmas tree production is available from State universities, agricultural extension agents, and Christmas tree growers associations.

Fruit and Nut Orchards, Berry Farms, and Vineyards

The complexity of establishing and managing an orchard, berry farm, or vineyard is beyond the scope of this handbook. Development of fruit or nut orchards, berry farms, or vineyards is a postmining land use that requires a highly intensive level of management. To be successful, the land manager must be knowledgeable about the crop he wishes to produce, or be willing to hire someone with that expertise. Any species of fruit, nut, berry, or grape that is indigenous to the region or has been introduced successfully has potential for use on a reclaimed mine site.

Planning the establishment of an orchard, berry farm, or vineyard before mining begins will ensure proper overburden placement, landforming, and site preparation. It is advisable to plant a cover crop for 1 or 2 years before attempting to establish fruit or nut trees, berries, or grapes. The site will be better stabilized, and the cover crops will help build a better soil structure.

Management of most horticulture crops requires gently rolling to flat terrain that allows complete access with tractors or trucks for spraying and transporting the harvested crop. Distance to market and road conditions between the mined site and the market are important considerations; some fruits and berries damage easily if transported over rough roads. An available and adequate labor force is needed because many activities in an orchard, berry farm, or vineyard are highly labor intensive. A good water source is needed for spraying and, where necessary, irrigation. Adequate acreage is needed to conduct a commercial venture, at least 200 to 250 acres for fruit orchards, for example. Other finer points of developing one or more of these horticultural activities should be obtained from experts in fruit, nut, berry, or grape culture.

Recreation

Recreation as a secondary use includes such activities as hunting, hiking, and bird watching. These activities can be enjoyed on lands reclaimed to forestry or wildlife with little or no modification to standard reclamation plans. If forestry is the primary land use, planned species diversity will enhance wildlife habitat and improve this type of recreation.

Trails for hiking and cross-country skiing would require slightly greater modification in the reclamation plan. However, the primary land-use objective would not be changed.

Other forms of recreation such as fishing, downhill skiing, camping, or activities requiring specialized facilities will have to be planned in advance of reclamation, preferably in the premining stage. These are mainly exclusive uses, but probably will occupy only a small portion of the area disturbed by mining. Fishing, for example, may require ponds with access roads and space for parking. If boating is included, launching ramps must be designed.

For campgrounds it is necessary to design a road system with parking spurs, and sanitation facilities must be considered. Skiing facilities require tows, a trail system, sanitation, and possibly concession stands. If the location is right, construction of a golf course or driving range is another option.

Where any of these structured recreation activities is the land use objective, the landowner is advised to engage the services of a competent designer to prepare plans and specifications for the desired facility.

Other

Other postmining land uses include those such as airports, housing developments, schools, shopping centers, and commercial buildings that are constructed primarily of concrete and steel. These land uses as such are not addressed in this handbook. However, these types of uses do require vegetation for land stabilization and erosion control before construction, followed by landscaping following construction. To that extend, revegetation activities considered within the realm of this handbook may apply.

EVALUATING REVEGETATION SUCCESS

Criteria for evaluating success of revegetation include ground cover, production, and stocking as appropriate for the approved postmining land use (Table 9). Other criteria, such as species diversity, approved in the PAP can be used to judge the effectiveness of revegetation.

Revegetation success may be compared against either reference areas or technical (performance) standards. With the reference-area approach, crop or herbage production and environmental protection (cover) on the reclaimed site is compared with the same parameters on a similarly managed and vegetated unmined site nearby that serves as the reference or standard for comparison. The technical-standards method of evaluating success consists of comparing production, cover, or stocking on the reclaimed area with an accepted performance standard appropriate for the postmining land use.

Reference Area Selection

Reference areas are unmined land units maintained under appropriate management to measure vegetation ground cover, productivity, and other parameters, such as plant species diversity, that are approved in the PAP. The selection of reference areas depends on the approved land use for the revegetated area. In many cases, postmining vegetation and land uses differ from premining vegetation and land uses. An example of this would be converting oak savanna grazing land to improved pasture of fescue or bermudagrass. In this case, the reference area would be an improved pasture of fescue or bermudagrass.

Reference areas represent the climate, geology, soil, slope, and vegetation in the permit area. Essential criteria for comparing revegetated and reference areas include:

- Individual site factors, including elevation, precipitation, slope, and aspect, are similar on both areas.
- Both areas are composed of the same plant life-forms and seasonal varieties of vegetation. A wooded area would not be a reference for pasture land.
- Management of the reference area during the revegetation phase is consistent with that proposed for the revegetated area. The condition class of the reference area (when dealing with rangeland) is the same as that desired in the management plan for the revegetated area, and indicates a stable trend.
- Certain edaphic characteristics are similar, though it is unlikely that the revegetated area will have exactly the same soils as the reference area.
- A revegetated area that is realistically comparable to the reference area, i.e., it can produce a similar kind and amount of vegetation.

It is not essential that the reference area be immediately adjacent to the revegetated area so long as these criteria are met. However, where the two areas are separated by too much distance (preferably not outside a radius of 20 miles), differences in rainfall distribution patterns, elevation, and other environmental factors could result in statistically different production, cover, and diversity values.

The size of reference areas may differ because of the many site variables involved. A recommended minimum size for hay and croplands is 1 acre, but larger areas (2 to 5 acres) are preferable because they better represent the variation in production and cover due to differences in nutrient availability, topography, drainage, and other site-related criteria. Reference areas suggested for grazing land are 5 to 10 acres in humid regions and from 20 to 100 acres or larger in semi-arid and arid range areas. Larger reference areas tend to better represent the variation and species diversity of an inventory unit simply because more space is available for more of the potential species to occur.

Several reference areas may be desirable. The number selected may correspond with the number of inventory units selected for each permit. However, each inventory unit that exhibits a wide variation in vegetation cover or production may need to be represented by more than one reference area. The number of reference areas chosen is more dependent on the variability of the premining vegetation than the size of the permit area. In most cases, at least one reference area per type of inventory unit (i.e., vegetation type, range site, or ecological response unit) is desired. The risk involved with using only one reference area is that the cover, production, and diversity values used to determine bond release may not represent the inventory unit adequately. Poorly selected reference areas, abnormal climatic conditions, fire, nontypical soil or topographic conditions, or biotic influences can contribute to the misrepresentation of an inventory unit. Thus, more than one reference area per major inventory unit is desirable.

Table 9. Criteria for evaluating revegetation success for postmining land uses.

Postmining Land Use	*Parameter*
Grazing land, pasture land, land occasionally cut for hay	Ground cover and productivity
Cropland	Crop production
Fish and wildlife habitat, recreation, shelterbelts, or forest products	Tree and shrub stocking and ground cover
Industrial or residential use	Ground cover
Areas previously mined and not reclaimed (orphan lands)	Ground cover

Technical Standards

This evaluation approach involves the comparison of technical standards of production, cover, or stocking with the same parameters measured on the reclaimed area. Resource agencies, such as the Soil Conservation Service (SCS) and the State Agricultural Extension Service, are sources of guidance in establishing standards. Primary sources on which to base production criteria are published yields for counties and/or soil- and range-site mapping units. Recent county soil survey reports published by SCS contain expected yields for forage and other crops by soil type. State crop reporting services publish average yields per acre by county (see examples in Tables 10 and 11). Unpublished crop-yield data from State Agricultural Experiment Stations often are available to extension agents.

Expected forage production and the important plant species on native rangelands are described in Range Site Descriptions available from SCS. Tree and shrub stocking (number of stems per acre) and ground-cover standards for nonagricultural areas are primarily based on recommendation of State and Federal agencies responsible for administering forestry and wildlife programs. Since orchards normally do not become productive within the 5-year responsibility period (above 26-inch precipitation areas), the use of reference areas or establishment of production standards is not appropriate for them. Orchard evaluation should be based on ground-cover requirements, appropriate stocking, and approved management of live trees (as recommended by State horticultural extension agent).

Table 10. Example of crop yield information available in soil survey reports.*

Soil Series and Mapping Units	Crop Yields† Corn A	Corn B	Wheat A	Wheat B	Soybeans A	Soybeans B	Alfalfa A	Alfalfa B	Pasture (forage) A	Pasture (forage) B
	Bu						Tons		Lbs	
Allen:										
AeC	48	75	34	51	23	35	2.1	3.3	2700	3900‡
AeD	46	68	30	46	—	—	2.1	3.1	2700	3600
AeE	—	—	—	—	—	—	—	—	2500	3400
AnD3	32	50	24	36	—	—	1.7	2.4	1800	3000
Atkins: At	35	50	—	—	22	30	—	—	1600	2700
Bewleyville:										
BeB	58	92	36	54	27	40	2.3	3.4	2300	3900
BeC	55	85	34	52	21	36	2.2	3.3	2300	3900
Bodine: BdF	—	—	—	—	—	—	—	—	1100	1800
Bonair: Bn	42	68	—	—	20	33	—	—	2100	3600
Bouldin: BoF	—	—	—	—	—	—	—	—	—	—
Christian:										
ChC2	42	60	32	47	17	21	2.0	2.9	2400	3300
ChD2	40	55	30	44	—	—	1.9	2.6	2200	3300
CnC2	40	56	32	44	16	20	2.0	2.5	2500	3300
CnD2	32	52	28	41	—	—	1.8	2.4	2100	3000
CnE2	—	—	—	—	—	—	—	—	1900	2700
CsD3	—	—	20	33	—	—	1.4	1.9	1500	2200
Curtistown:										
CuB	75	115	38	54	28	43	2.6	3.8	3000	4500

*Adapted from USDA Soil Conservation Service, 1981.

†Yields in column A are those obtained under common management; those in column B are to be expected under a high level of management. Absence of yield indicates crop is not suited to the soil or is not commonly grown on it. Production units are per 1 acre.

‡These values were converted from cow days/acre by assuming 20 pounds of air-dry forage is required for one cow for one day.

Table 11. Examples of yield data from State crop reporting services (Alabama counties, 1977-78).

County	Yields Corn	Soybeans	Wheat	Hay
	Bushels/acre			Tons/acre
Bibb	26	22	26	2
Blount	37	24	34	2
Cherokee	34	23	28	2
Choctaw	31	25	17	2
Cullman	27	24	31	2
DeKalb	36	23	29	2
Etowah	40	25	36	1
Fayette	30	21	29	2
Franklin	35	21	26	1
Jackson	35	22	27	1
Jefferson	23	24	33	2
Marion	36	22	24	2
Marshall	43	20	24	2
Morgan	35	19	25	2
Shelby	22	21	33	1
St.Clair	36	21	27	2
Tuscaloosa	19	20	27	2
Walker	21	26	28	2
Winston	30	19	29	2

Mapping

A map is a basic tool for delineating areas of similar vegetation (inventory units) on permit areas (both before mining, where required, and after revegetation) and on reference areas and for locating and laying out sampling points or sites on the inventory units. On permits where revegetation success is judged by technical standards, mapping is needed primarily to delineate the areas of different postmining land uses. Where reference areas are used, vegetation near the mined area may need to be mapped to delineate vegetation types similar to those that were on the permit area before mining. Mapping is best accomplished by on-the-ground investigation with the aid of aerial photos; soil survey maps; topographic maps; and other resource maps, such as those that show range sites, pasture, and woodland suitability groupings appropriate to the vegetation communities involved.

Vegetation Sampling

In most situations, some method of sampling is needed to measure the required vegetation parameters on reclaimed areas and, where necessary, on reference areas. Exceptions are where production is determined by harvesting hay, ensilage, or other crops or where stocking is measured by counting woody plants on an entire inventory unit. In such cases, calculating a statistical confidence interval is not appropriate because no sampling technique is used. Sampling also may be unnecessary on areas where it is obvious that ground cover and stocking of woody plant stems exceed approved success standards.

Principles of Sampling

Vegetation sampling is a means for making inferences or conclusions about a plant community based on information obtained from examination of a small proportion (sample) of that community. Ideal sampling techniques are repeatable, accurate (i.e., capable of revealing the true characteristics of the plant community), efficient, and convenient and easy to use (i.e., provide accurate information with minimal expenditure of labor and time in devising and executing).

Table 12. A set of random numbers.

Column 1	Column 2	Column 3	Column 4
6327	0983	3798	4679
2167	6484	9467	9058
5939	0407	1804	8827
4672	3865	5689	9878
8071	5185	5514	5308
9509	0603	7461	8850
6615	2588	3558	3349
4833	2422	9790	1183
5594	1809	6931	6571
9441	1699	3947	7702
7922	9812	7229	5252
9419	6494	8179	8065
6178	3556	2466	2495
2647	3961	7546	4799
0474	1839	6926	6534
9814	1577	8293	0301
0104	4579	0627	8667
1608	9470	4131	5345
9722	1557	0471	5498
4189	3582	3675	9461
9855	8088	9006	6897
5791	8234	1472	3421
0872	3310	0510	9046
8953	9809	8037	8376
2895	4319	6544	8953
0609	5248	8734	2498
9795	2464	6170	1063
1572	7371	7936	2841
4307	0294	6060	5194
4857	0197	2401	7005
1632	7189	6463	9830
0745	8034	7882	7152
0736	5110	5165	6571
8168	7924	5876	1407
7468	5313	2736	9010
6044	5420	3077	9070
6716	0059	3001	8871
9342	0169	6880	7986
5809	6048	9051	1151
1532	9715	7081	0109
5506	5812	5917	4415
4045	1751	2817	9958
5966	9930	6437	7279
6062	3296	5093	2503
4097	8379	5670	0614
6793	3999	4645	5143
7960	4853	0583	1920
1321	4067	8503	1604

Statistically sound vegetation sampling procedures incorporate the concept of randomization. The basic purpose of random sampling is to allow each observation or data collection unit an equal chance of being included in the sample. This is needed to provide an unbiased estimate of the mean and variance (indicator of variability) of the vegetation characteristics for making statistical comparisons. The purest form of random sampling is called simple or completely random sampling. Theoretically, simple random sampling is the most unbiased and statistically clean, but it is seldom used as a self-sufficient sampling design because it usually is less efficient and less practical than other sampling designs, especially in terms of time needed to devise and execute in the field.

Systematic (nonrandom) data collection designs, on the other hand, usually are more time and cost efficient but cannot be used to obtain unbiased data unless stratification or other procedure of random selection is incorporated at some stage of sampling. Thus, most designs for sampling vegetation integrate some degree of systematic sampling or stratification with random sampling. Such designs are called stratified sampling or stratified random sampling.

There is a wealth of literature that discusses the relative merits of simple random sampling and stratified random sampling designs. Most of these designs are considered valid for making statistically unbiased estimates of the population. Regardless of the type of design, the basic and most important consideration in sampling is that the sample points are selected objectively and without bias by the investigator. In addition, sample points should be distributed throughout the sampling units and not just within a small portion of the sampling units. They also should be located far enough within the sampling unit to avoid transition zones and edge effects created by highways, rivers, etc.

Selecting random sample points objectively is best accomplished by using a table of random numbers (Table 12). To use a list of random numbers, select an arbitrary, objective starting point anywhere on the table. Select subsequent numbers by progressing in order down the column.

Each digit within a random numbers table is a random number, though random numbers commonly are given as four digits. If the bottom of column 2 were selected as a starting point, 4067, 406, 40, or 4 could be used as the first random number. The units of measure used for locating the sample points (spaces, meters, feet, and so forth) will determine the size (number of digits) of the number selected. The same sequence of numbers always should be selected, and zeros should be counted as one of the digits.

Sampling Designs

It is not the intent of this handbook to recommend a universal sampling design or the statistical manipulations that go with it. Many references are available that provide guidance and details on sampling systems and the statistics needed to handle the data. Examples of several sampling designs are in the section that follows. These designs—simple random, stratified or restricted random, and systematic sampling with multiple random starts—allow the calculation of a valid estimate of the variance of the mean and can be adapted to most of the techniques used for sampling cover, production, and stocking. The specific design chosen depends somewhat on the parameter under investigation and on the sampling method used.

Random Location of Sample Points

The location of random sample points is depicted in Figure 22. The procedures for selecting random sample points are:

1. Select two random numbers as described previously. The first number chosen is used as the distance along the x axis and the second as the distance along the y axis.
2. Locate the x coordinate by pacing or measuring the random number distance along the x axis from the point of origin. From the x coordinate, pace or measure a line perpendicular from the x axis and equal to the random number distance along the y axis. The point at the end of the line is the random sampling point. A perpendicular line from the y axis to the random sampling point is equal to the distance that was paced along the x axis. A sample point that falls outside of the sampling unit is not used.
3. Return to the point of origin, select the next two random numbers, and repeat the process described. Continue this process until all sample points have been taken.

The preceding method suggests that the sampling points will be located directly in the field at the time that the vegetation is sampled. This method also can be used by first locating the sample points on an aerial photograph or map. Location of the axes along cardinal compass points will facilitate the rest of the procedure. Once all of the sample points are located on the map, the most convenient itinerary or travel path to all points is determined and shown on the map (Figure 23). Directions for locating the sample points in the field are then written on the map. These directions include the compass bearing and distance from one point to the next, beginning from the origin of the reference axes. The person(s) doing the field sampling will need a compass and measuring tape (pacing may suffice) to locate each point per directions on the map.

As seen here, a simple random design can be tedious and time consuming to devise and execute. Designs incorporating both systematic and random sampling procedures often are more time and cost efficient than simple random sampling. They also provide an unbiased estimate of the population mean and a valid basis for computing sampling variance.

Stratified Random Design Using a Baseline

The procedure for locating random sampling points using a baseline is shown in Figure 24. The following describes this procedure:

1. Locate a baseline either through the middle or along one edge of the inventory unit. Points along this line are spaced a predetermined and equal distance apart,

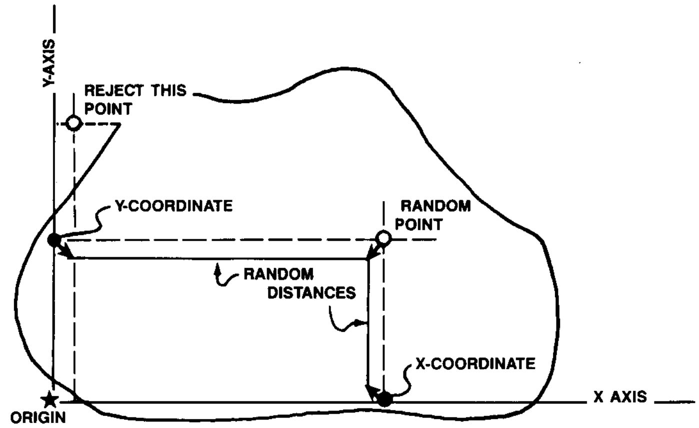


Figure 22. Random location of sample points on map or in field (from Knight 1978).

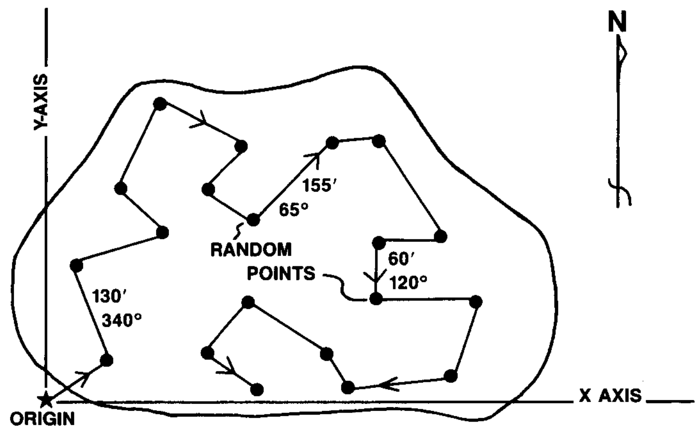


Figure 23. Sample points can be located in field by compass directions and distances from coordinates randomly selected on a map. Connected points show least-effort travel path. (Adapted from Raelson and McKee 1982).

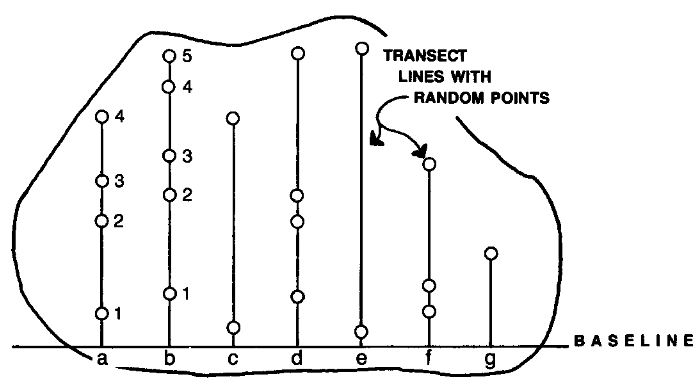


Figure 24. Stratified random design using a baseline (from Knight 1978).

such as 100 feet.

2. Proceed to the first point (a) on the baseline and select a random number. This number is the distance to the first sample point (1) on a line running perpendicular to the baseline. Where the baseline is located in the middle of the area and the random number is even, the sample point is located to the right of the baseline; if it is odd, the sample is located to the left. The second sample point is obtained by choosing a second random number that is the distance to point 2 from point 1 along the same perpendicular line. Additional points are located in the same manner until the perimeter of the inventory unit is approached. The investigator then returns to the baseline and proceeds to the second predetermined point (b). Sample points are then located along a line perpendicular to this point as described. The procedure is repeated until an adequate sample has been collected.

Random numbers that result in the overlap of sample plots should be disregarded in most sampling situations.

Systematic Sampling with Multiple Random Starts

Systematic sampling with multiple random starts is an efficient method of locating sample points that still allows a valid calculation of the variance of the mean of the measured vegetational characteristics, even though it utilizes systematic sampling (Shiue 1960). This method can be implemented using a baseline and is similar to the stratified random method shown in Figure 24. The procedures for establishing sample points using this method include the following:

1. Locate a baseline either through the middle or along one edge of the sampling unit. Points along this line will be spaced a predetermined and equal distance apart.
2. Proceed to the first point on the baseline and select a random number. The random number is the distance to the first sample point along a line running perpendicular to the baseline (transect line).
3. Locate subsequent points a predetermined and equal distance apart along the transect line. Discontinue sampling along the transect line when the perimeter of the sample unit is approached.
4. Return to the baseline and proceed to the second predetermined point. Sample points are located along a transect line perpendicular to this point as described. The distance to the first sample point is once again determined by the selection of a random number. Continue in this manner until an adequate sample has been taken and the entire sample unit has been sampled.

Where the baseline is placed in the middle of the sample unit, transects are placed on both sides of the baseline by the procedure described for the stratified random design. A minimum number of random starts is six, but more are preferred.

Modifications can be inserted in the preceding designs to add randomness, but each addition increases the time required to devise and use the design. For example, points along the baseline could be selected by using a restricted random procedure where one of several (suggest 3) equidistant points within each 100-foot segment is chosen randomly as the beginning point for the transect line. Similarly, each sample point on the transect line could be chosen randomly from several equidistant points within segments of a prescribed equal length.

Measuring Ground Cover

Concepts

A definition of ground cover appropriate to mined-land revegetation is "the area of ground covered by the combined aerial parts of vegetation and the litter that is produced naturally on site, expressed as a percentage of the total area of measurement." In a strict sense, cover by aerial parts can be viewed as the vertical projection of all aboveground standing plant material or vegetation onto the ground surface (Figure 25). Obviously, at any given time, this may include some standing dead plant material. Litter, the dead fallen organic material, is included in ground cover because it, like living and dead standing vegetation, also protects the ground surface from raindrop impact and erosion.

According to the strict definition of vegetative cover given, the many small openings that are not actually overlain by plant parts within a canopy are not counted as cover. Aggregated over a large area with many plants, these small uncovered interstices can account for a sizeable percentage of the total ground area. On the other hand, where a loose definition of cover is used, all of the area within the vertical projection of the perimeter of the canopy of a plant or group of plants is included as cover and a larger estimate of cover is obtained than where the strict definition is applied (Figure 26). One important function of vegetation cover is to reduce splash erosion by intercepting and dissipating the energy of raindrops. Openings within a canopy may allow raindrops to reach bare soil and affect the amount of splash erosion or control of it. As discussed later, techniques that measure cover as defined by the loose concept of cover usually are more sub-

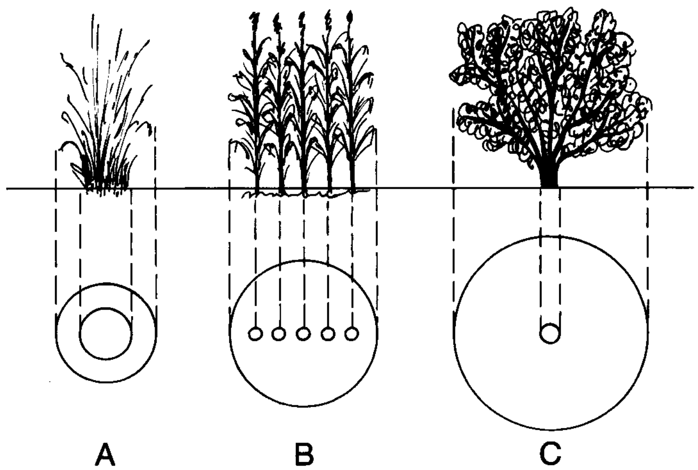


Figure 25. Difference between maximum spread of foliage (aerial cover) and basal area for (A) bunchgrass, (B) sod-forming grass or stand of single stem plants, and (C) forb, shrub, or tree.

jective than techniques that measure it by the strict definition.

Comparing ground cover on a revegetated area to an approved standard requires that the revegetated area be sampled with the same methods and units of measure that were used to establish the standard. Cover data can be collected by species, by life forms (grasses, forbs, shrubs), or for all vegetation as a whole. Rocks on the surface, though not included as ground cover by definition, do contribute to protecting the surface from raindrop impact and other erosional processes.

Where reference areas are used, cover is a valid comparative measure only where both the reference and the revegetated areas have received equal levels of utilization or none at all. For example, it is conceivable—even though livestock grazing is not part of the management plan—that one area or other could be browsed or grazed selectively by deer because of a difference in species composition or nutrient content of the forage. In such situations, valid comparisons cannot be made between the two areas.

The distribution or evenness of vegetational cover also is an important consideration in assessing revegetation success. In fact, distribution of cover may be more important than the average overall cover. Control of erosion is more likely to be effective and complete where revegetation is distributed uniformly over an entire area than where patches or small areas with substandard cover or no cover are present. A potential hazard is that erosion, especially gullies, may begin in the unvegetated patches and spread or cut into adjoining vegetated areas. It is probable that erosion and siltation will be greater from one or two sparsely vegetated or unvegetated ¼-acre patches, for example, within an otherwise adequately vegetated area than from an uniformly vegetated site that has less average cover overall. An unvegetated or poorly vegetated area 50 by 200 feet (about ¼ acre) lying lengthwise up and down a steep slope could potentially transform into an expanding gully that would require considerable effort to repair and stop. The maximum size that could be allowed for any one patch of substandard cover should vary according to soil, slope, and other sites conditions. An unvegetated strip running lengthwise up and down a steep slope is more likely to severely erode than a similar-size strip running contour on a gentle slope or on level ground.

Estimating Cover Visually

Normally, the simplest and fastest way to evaluate ground cover is by visual or "eyeball" estimation of the entire area in question. It also is the most subjective, least accurate, and least repeatable of any estimation method used. Even among trained observers, estimates of cover on a given area may differ by 25 percent or more. Cover estimates by a single observer may be inconsistent from day to day or even throughout the day. Visual estimates of ground cover by most observers become more accurate as the cover approaches 0 or 100 percent and less accurate as the cover approaches 50 percent. Usually, it is with ground covers near this mid range that an accurate measure will be most needed for determining eligibility for bond release.

The accuracy of visually estimating cover on large areas can be increased by sampling with randomly or systematically placed small plots known as quadrats. The quadrat usually is delineated by a frame placed carefully on the ground so that the natural position of the vegetation is disturbed as little as possible (Figure 27). Sample plots or quadrats 1 m² in area often are used, but the size and shape can be varied to suit the structure of the vegetation being

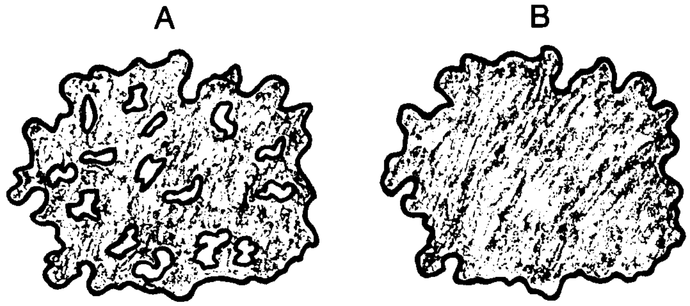


Figure 26. An illustration of (A) the strict definition of vegetative cover (the white areas inside the plant or plant community canopy are not covered) and (B) the loose definition of cover.

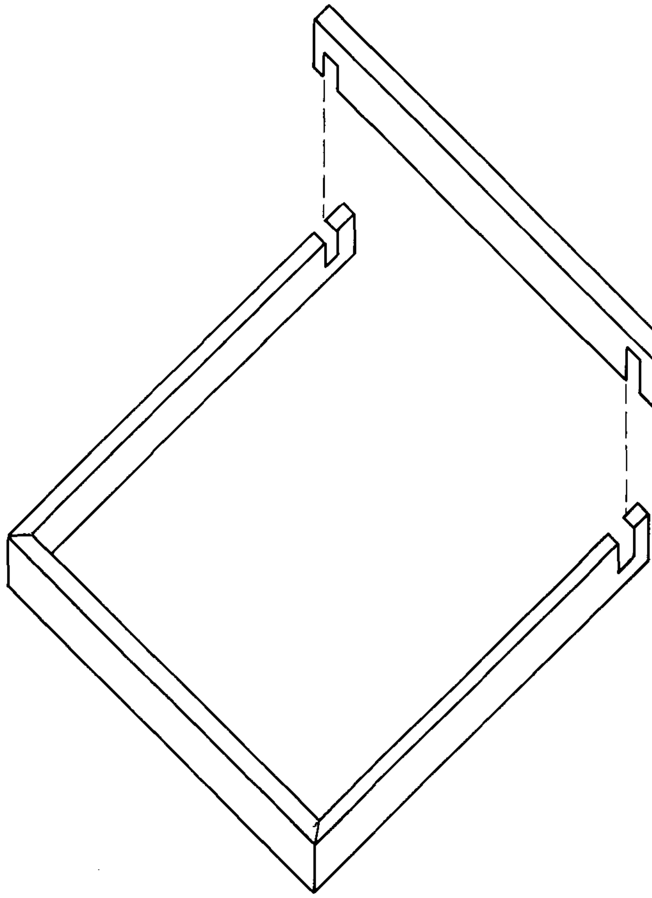


Figure 27. Quadrat frame with removable side to facilitate placement in vegetation. The frame can be constructed from 1/8- × 1-inch strap metal.

evaluated and the convenience of the observer. Where production is to be measured, the same quadrat may be used for sampling both cover and production. Quadrats are located within inventory units by one of the sampling designs discussed.

Accuracy is gained by using quadrats because it is easier to see and estimate ground cover in small defined plots than in large areas. Sampling with quadrats also provides the opportunity for statistical analysis. The final cover value is a mean of the quadrat estimates, and an estimate of error and statistical confidence can be determined. Some ecologists have shown that quadrat size or shape does not significantly influence the visual estimate of cover, and that sampling adequacy is achieved more easily by increasing the number of observations rather than increasing quadrat size. Accuracy in estimating cover with quadrats can be improved somewhat by placing marks equidistant along each side of the quadrat frame to delineate the outside points of an imaginary grid (Figure 28). The observer then envisions the number of grid units that are covered or filled by vegetation and litter. This can also help the observer by providing a reference for the smallest unit of estimation (e.g., 5 percent). Even with these aids, observers still tend to overestimate ground cover because it is difficult to accurately account for the openings within and among the foliage of an individual plant or closely spaced groups of plants.

Training is required for an observer to become proficient at estimating cover visually. For training purposes, cover estimated by the use of quadrats can be compared with cover measured by a number of points (as described for the point-quadrat method) placed randomly within the quadrat.

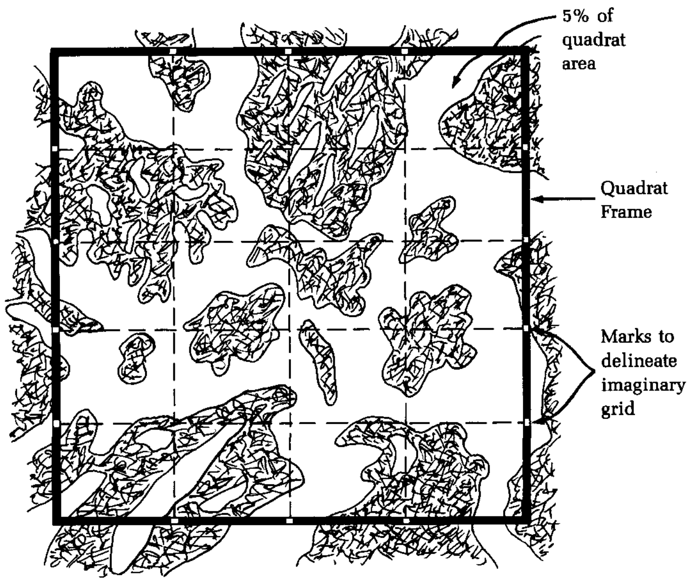


Figure 28. A small plot or quadrat can be used to aid in the visual estimation of ground cover. Marks on the frame can help the observer envision an imaginary grid and provide a reference for the smallest unit of area estimated (5 percent).

Point-Quadrat Method

This method for measuring cover also is called point-intercept, point-hit, point-frequency, point analysis, point drop, or point. The point-quadrat method reflects the concept of reducing the size of a quadrat to a point, e.g., a quadrat virtually without area or, at most, a very tiny area. The method involves the recording of a "hit" or "miss" on vegetation or litter at a point defined by the sharpened tip of a rod or pin that is lowered vertically through the vegetation canopy. The contact point also can be defined by sighting through an optical device such as a sighting tube equipped with crosshairs. One inconvenience with using either a sharpened pin or sighting tube is that a supporting frame is needed in the field to hold and steady them and provide vertical alignment.

The point-quadrat is an accurate, repeatable, and reasonably objective method for measuring aerial and basal cover, but it has several limitations. With the measuring techniques and gadgetry normally used, the method is limited to measuring relatively low-growing herbaceous and dwarf-shrub vegetation. Thirty inches is about the maximum height that can be measured effectively or conveniently. To overcome this problem, an optical instrument has been developed that allows point-hit measurements to be taken in vegetation of any height (Vierts 1985). Point readings made with any device can be difficult to obtain when vegetation is moving in the wind.

In practice, a frame designed to hold several pins or one designed to use a single pin to make several readings has been used most often (Figure 29). The frame must hold or guide the pins at two places so that a stable, nearly vertical alignment of the pins is maintained as they are lowered to the ground. Any change from a fixed angle of vegetation interception can alter results, so it is important that all readings be done with the frame in the same position.

To measure cover, only the first contact by the point of the pin on vegetation or litter need be recorded. If the point contacts both vegetation and litter, there is only one recording made. Similarly, only one "hit" is recorded even where several contacts with vegetation are made by the point of the pin as it is lowered to the ground. However, where additional information is desired about the plant community, such as composition, structure, basal area, and ground surface cover, all contacts of the point with aerial vegetation and whatever is encountered at ground level can be recorded. Recording hits on the basal area of plants may be desired because basal area is considered a better indicator than aerial cover for determining trend or changes in the condition of rangeland. Recording all hits by species or life forms (grasses, forbs, half shrubs) can provide information about the composition and diversity of the plant community.

The optical-point bar is a recently developed instrument for measuring cover by the point-quadrat concept. This optical device has a set of 10, low-power, short-focus scopes that replace the standard set of pins. A fine wire crosshair is located precisely between two lenses in each scope to provide a parallax-free image similar to that from a rifle scope, but with a short infinite focus point. The main advantage of this instrument is its usefulness in vegetation of any height. It is faster and slightly more accurate than the conventional pins and frame device, but is much more expensive than pin and frame devices (Vierts 1985).

Size of Point

One potential source of error in precisely measuring cover with the point quadrat is the diameter of the pin. The nearer a point or tip of a pin comes to having no area, the more precise the measurement. Goodall (1952) found consistent bias toward larger estimates of cover as pin diameter increased. The amount of increase was partly related to the morphology of the plant species measured. Estimates of grasses were more affected than broad-leaved forbs by an increase in pin size. Thin intersecting cross-hairs in a sighting tube have been shown to be better than pins for defining a point. In experiments, a sighting tube also gave slightly better repeatability between observers than pins supported in a frame; it also gave lower estimates of cover than pins.

Single Versus Multiple Placement of Points

Binomial theory serves as the statistical basis of point-quadrat cover analysis. This applies only if all sample points are placed randomly and independently so that any point on the reference area has an equal chance of being chosen. For convenience in sampling, however, methods often are used that include restricted randomization in point selection and systematic placement of points. One form of systematic placement of points is the point frame device. In fact, the point-quadrat method most often is used with a frame that holds several (usually 10) evenly spaced pins (Figure 29). The 10 pins within each frame position or setting are not placed independently of each other. Rather, their placement is fixed within a restricted area; only one of the pins could be considered as being placed independently. As a result, more points are needed

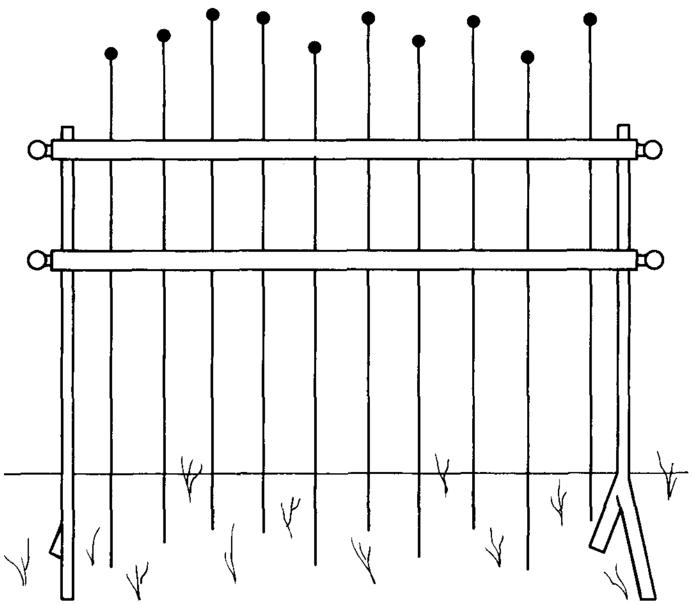


Figure 29. Frame with pins for measuring cover by the point-quadrat method.

Table 13. Values of 95 percent confidence intervals for the binomial sampling distribution with p = 70 percent (modified from Snedecor, 1946).

Confidence Interval (%)	*Sample Size (No. Points, n)*
39–95	10
46–88	20
56–82	50
60–79	100
64–76	250
67–73	1,000

when aligned in frames to achieve the same level of statistical precision as obtained with single points placed independently.

The number of points required to achieve a given level of statistical precision always was less with pins placed independently than with pins in frames (Goodall 1952). Depending on amount and type of cover, from 568 to 902 independently placed points gave the same level of statistical precision as 2,000 framed pins (200 frame positions). However, locating and placing 200 frames may be easier and less time consuming than locating and placing 600 to 900 individual points; thus, the efficiency of using frames seems to compensate for the greater number of total points required.

Binomial theory does not apply to cover estimates made by using frames of pins. It is better to consider each frame as a sample observation that can have a value of 1 to 10. Such samples would fit the normal distribution. The standard error of observations from pin frames can be calculated from the data and using simple equations given in any introductory statistics book.

How Many Points Are Needed?

The number of sample points needed to estimate cover usually is based on a trade-off between the desired level of precision and the time available and required for making the estimates. One consideration is that the number of sample points necessary to make a precise estimate of cover is independent of the size of the area to be examined. Whether the study area is 1 acre, 100 acres, or 1,000 acres, the same number of randomly chosen points will give the same level of statistical precision in each case. This is so because all sites are composed of an infinite number of dimensionless points. In all cases, the same finite number of sample points is chosen randomly so that the relation between sample size and population size is the same. Again, it is important that sample points are chosen at random.

An important factor in choosing the number of sample points is that, as the number of sample points increases, the precision of the estimate of the mean also increases; but this precision increases at a decreasing rate.

Table 13 shows the confidence intervals for the 95 percent level of statistical confidence for a binomial distribution centered at $p = 70$ percent (the desired cover). As the number of sample points used to make the estimate of 'p' increases, the confidence interval narrows. When only 10 sample points are used, any sample cover value between 39 and 95 percent is within the limits of 95 percent statistical confidence for a true cover value of 70 percent. It is unlikely that this level of precision would be acceptable for ascertaining if the desired cover is achieved. When 1,000 sample points are used, the confidence interval is greatly reduced, to 70 percent plus or minus 3 percent. This is an acceptable level of statistical error but it could take a long time to examine 1,000 sample points.

The use of 100 sample points might be an acceptable compromise. Data from 100 sample points produces a confidence interval which is suitably narrow for many purposes. When 100 sample points are used, the number of points that intercept vegetation is the value of cover, i.e., the percentage of the ground surface covered by vegetation. Additional discussion on the theory and statistics for handling of point data can be found in Realson and McKee (1982) and other references listed in the Bibliography.

Step Transect

The step transect method can be used for estimating cover at points placed randomly or systematically. In this method, the observer paces across the area to be sampled and the presence or absence of vegetation at a point on the tip of the shoe is noted. A small mark or notch on the tip of the shoe sole can help define the sample point. The occurrence of vegetation, litter, or bare ground can be noted at each observation point to help define distribution of cover. The number of steps between observations can be systematic or varied. It is necessary to lay out one or more random 'walks" to cover the area to be evaluated.

The step transect method is much less precise than using pins in a frame or a sighting tube with crosshairs. It also can introduce bias in that the position of the vegetation can be altered as the foot is placed on the ground. Some judgment must be used to compensate for this situation. However, the step method is fast and relatively easy to use and does not require carrying, handling, or positioning a measuring device. Some of the loss of objectivity by this method can be compensated for by increasing the number of observation points.

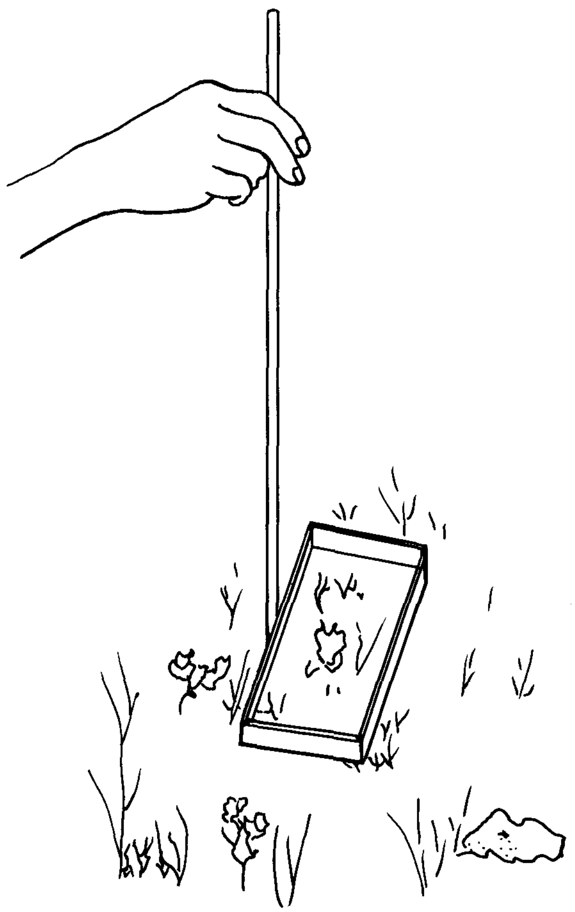


Figure 30. A tiny quadrat is used for estimating ground cover by the rated microplot method.

Rated Microplots

The use of rated microplots takes the concept of the imaginary grid as with the visual estimation of cover with the aid of quadrats, and, as shown in Figure 28, applies it to very small plots (0.5 to 2.0 square inches). The microplot frame is held with a rod attached to it perpendicularly and placed just above the vegetation to be measured (Figure 30). The microplot can be square, rectangular, or circular, but circular plots may be more difficult to subdivide visually. The microplot is arbitrarily subdivided into units such as quarters or tenths, and cover is estimated visually and rated to the nearest subunit (one-quarter or one-tenth) of area occupied for each of the items viewed in the microplot. For example, assume ratings will be made to the nearest one-tenth; then, if vegetation as viewed when looking down through the microplot occupies about four-tenths of the area of the microplot and litter (without vegetation above it) is viewed to occupy an additional two-tenths, a cover rating of 6 (4 vegetation + 2 litter) would be given. Items such as basal area, rocks, and species also can be rated and recorded if such information is desired or needed. A number of readings would be taken on an inventory unit by following one of the sampling designs discussed previously.

In some experiments with several sizes and shapes of microplots, no difference in estimating cover was found among four sizes or between round and rectangular plots. They all provided results similar to the point-quadrat for estimating cover of most vegetation forms and ground-surface items (Morris 1973). A ½- by 1-inch microplot was a good compromise of the plots tested but had no advantage over an 0.8-inch-diameter circle. The rated microplot requires less time than point-quadrats for estimating cover.

Line-Intercept

The line-intercept method is useful mainly for measuring aerial cover of plants and clumps of plants with well-defined canopies and nearly solid crown cover and plants with relatively large basal areas. It is, therefore, more suited for measuring aerial cover of shrubs, small trees, and some forbs than for grasses and most forbs. In mixed communities of grasses and shrubs, it may be desirable to use the point-quadrat or other methods for estimating

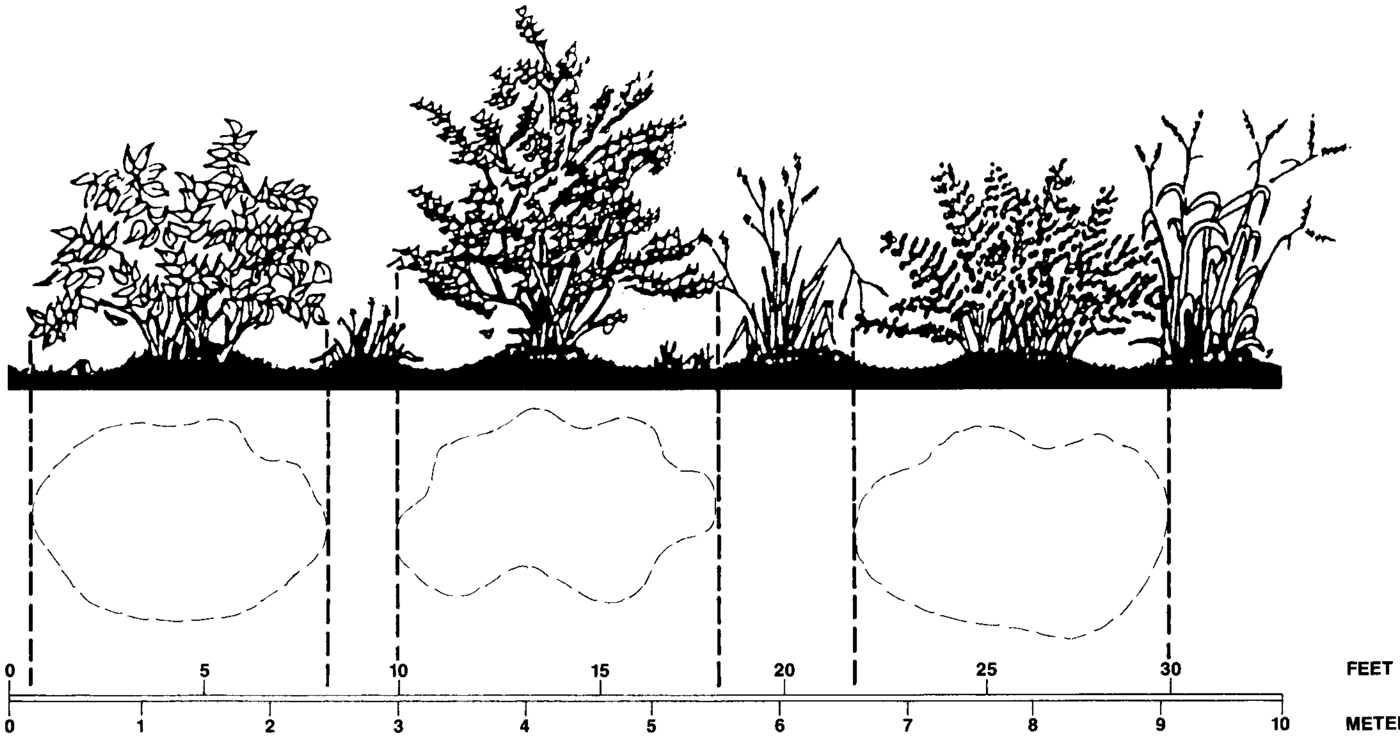


Figure 31. The line-intercept method is best suited for measuring aerial cover of shrubs and similar vegetation with closed, well-defined canopies.

cover of herbaceous vegetation and the line-intercept method for measuring shrubs. Quadrat frames could be located randomly along transect lines laid out to measure shrub cover.

The methodology for the line-intercept is as follows:

1. A line of predetermined length, preferably a tape measure, is stretched tightly across the vegetation or beneath the canopy of taller shrub and tree vegetation. Some type of clamp or holder anchored in the ground is needed to secure the tape on each end. The lines should be located objectively. The best sampling design is a stratified-random one using a baseline with transect lines perpendicular to it.

2. The canopy intersect of each species along the line is measured directly from the tape or with a rule (Figure 31). Where canopies overlap in layered vegetation, it may be desirable to measure the layer at each height separately. The interception along the tape by canopies that are not solid should be interpreted consistently. For example, do not measure as cover the gaps between branches that extend across the tape. Small gaps within the plant canopy can be included as cover.

3. Transect lines can be between 35 and 350 feet long, but many short lines usually are preferred over a few long ones. Short lines are easier to hold and secure in place, but more time is required to locate, place, and move many short lines than a few longer ones. A minimum of 5 to 10 transects usually is required for adequate sampling. Guidance on the determination of sample size is given in Chambers and Brown (1983), Farmer et al. (1981), and other references cited in the bibliography.

4. Percent cover can be calculated for each species, or all species combined, by dividing the length of line intercepted by each or all species by the transect length and multiplying by 100. For an entire inventory unit, percent cover is the sum of the intercepted lengths from all transects divided by the total length of transects sampled, and multiplied by 100. Data are summarized by each transect line for statistical analysis.

Photographic (35 mm Slide) Method

Aerial cover of vegetation also can be determined with the use of 35 mm slides. Individual sample quadrats are first photographed in the field. Later, the percent of the quadrat covered is determined from a grid onto which the developed slide is projected. The procedure is as follows:

1. Sample quadrats are located randomly in the inventory unit by any one of the sampling designs described. The same quadrats used to photograph cover can be used to sample production, but cover must be photographed before production is sampled.

2. The quadrat is labeled according to location, data, and quadrat number. Labeling can be accomplished with individual cards for each quadrat, or a film imprinting system such as the Recordata Back available for Olympus cameras can be used.

3. A tripod and camera bar are used to position the camera vertically over the center of the quadrat. The size of the camera lens used is determined by the size of the quadrat. When viewed through the lens, the quadrat

should encompass the majority of the area outlined in the lens without distortion.

4. The focus, lens aperture, and shutter speed are adjusted for each quadrat and the photograph is taken.

5. The processed slide is projected onto a grid with 100 squares. The vertical and horizontal axes of the grid must coincide with the axes of the quadrat frame. The slide projector is adjusted so that the area within the quadrat matches exactly that within the grid.

6. The number of grid squares covered by vegetation, litter, bare ground, rock, and gravel are counted. The number of squares counted is equivalent to the percentage of each cover category within the sample grid. In sparse communities where individual plants can be identified from the slide, it may be possible to obtain percent cover by species.

7. Data are summarized by quadrat for statistical analysis. Percent cover can be derived for each of the cover categories (total vegetation, litter, bare ground, rock, etc.). In some cases, percent cover also can be determined for life forms and or species.

Other considerations for the use of this method are:

1. The 35 mm slide method is not well suited to sampling schemes that require large quadrat sizes. Quadrats larger than about 0.5 m^2 will not easily fit within the area encompassed by standard lens sizes.

2. This method is not well suited to tall vegetation (over 1 m). In mixed communities of grasses and shrubs, the 35 mm slide method can be used to assess grass and forb cover, and the line-intercept method used to evaluate shrub cover.

Evaluating Production

Several definitions or interpretations can be applied to vegetation production depending on the use or purpose of the vegetation, the plant type or life form, the approved standard for success, or other factors. Production often is defined in a broad sense as the current-year's growth or yield of aboveground plant material (biomass) on a unit of land. This definition may be applicable where total plant growth provides a meaningful measure of production for the plant species and land uses involved, such as grasses and forbs on grazing and pasture land or sorghum and corn grown for silage. However, this definition applies only where production on the vegetated area is compared with a success standard based on total biomass yield. This is most often done where reference areas are used as the success standard. In those situations, production is estimated usually by harvesting all of the current-year's growth of aboveground vegetation from within a sampling quadrat or plot of known area.

This definition does not apply to cropland and hayland where the intended produce is a specified part of the plant's growth or biomass such as seed (grain), fruit, and hay. It also does not fully apply for grazing and pasture land uses where production of the revegetated area is compared to technical standards that are not based on total biomass yield. For example, in the management of hayland, all of the aboveground biomass normally is not harvested, nor is all herbage grazed off in the proper management of grazing land. To properly compare production on vegetated areas with technical standards requires that the revegetated area be harvested or sampled in the same manner as the areas on which the standards are based. This emphasizes that standards and terminology should be clearly defined and understood by all parties concerned with the development of production success criteria.

Where defined as all of the current-year's growth (biomass), production includes diameter growth of stems and branches of trees and shrubs, and may, depending on interpretation, include persistent green, living leaves of evergreen plants. However, measurement of these stems, except possibly twig growth on shrubs, normally will be of little concern in evaluating the success of revegetation. Of primary concern is measuring production of vegetation grown for grazing, pasture, and cropland uses.

Harvest Sampling Method

Except where crops are harvested from an entire area, production most often is estimated by harvesting or clipping vegetation in sampling plots or quadrats of known size. Location of quadrats on inventory units can follow one of the sampling designs described previously. Estimates of cover usually can be made at the same location and same time as production estimates. Vegetation can be clipped by species, by life forms or other groups of species, or all together depending on objectives and requirements for data collection. Harvesting can be at different heights or for different parts of the plant depending on the crop, land use, success standard used, or other objectives. For example, in sampling for production of hay, where success is compared against a technical standard, the height of clipping above the ground should be the same as that normally used in mowing hay of that species in that locality. Where production on areas revegetated for pasture or grazing use is compared with reference areas, the sampled vegetation is clipped at ground level or as close to it as possible. Shrubs, if present, usually are not harvested in such a manner. However, directives may be given in the PAP to determine production of current-year's twig growth.

Following are several factors that may need to be considered when harvesting sample plots of vegetation. Some of these may cause problems and require extra effort to avoid or overcome.

1. What to Harvest—Two options are available in determining which plant material to include and exclude when clipping quadrats. One option is to harvest all plant material within an imaginary three-dimensional volume (cube or cylinder) projected above the quadrat even though the plant may not be rooted within the quadrat. Similarly, portions of plants rooted in the quadrat but overlapping outside the quadrat and not occupying space above it are not included in the harvest from the quadrat. This is called the 'volume concept" (Figure 32). The other option, called the 'basal concept," requires the clipping and saving of all parts of all plants rooted within the quadrat even if portions of the foliage of these plants overhang outside the quadrat. Parts of plants overhanging into but not rooted in the quadrat are not clipped. Where the quadrat boundary divides the base of clumpy-type plants, such as

bunchgrasses, only the portion of the plant based within the quadrat is clipped (Figure 32). The volume concept may have some merit and may be useful without too much difficulty in some vegetation types or structures. However, for sampling most vegetational types, it has less practical substance and injects more human error and bias than clipping by the basal concept. Attempting to delineate the boundaries of vegetation in an imaginary cube or cylinder in waving tall grass, for example, is more difficult and injects more bias than delineating which plants are rooted in or out of an easily visible quadrat frame on the ground. Also, placing the frame on the ground can alter the natural position of the aerial portion of the vegetation, but would have little effect on the selection of plants rooted in the quadrat.

2. Dead Vegetation—To measure only current year's growth (production), the dead standing vegetation should be removed from the harvested samples. This can be tedious and time consuming and it also injects bias. One possible way to avoid including dead vegetation is to randomly select and mark quadrat locations and clip off all dead vegetation shortly before the growing season begins. All of the vegetation harvested at these spots at the appropriate time later in the season would be considered as current-year's growth. One potential problem is that these spots could be selectively grazed by deer or other wildlife.

3. Protection From Grazing—Where grazing is to be practiced on inventory units, the vegetation should be protected from grazing animals at the location to be clipped. This would require use of exclosures or small cages built strong enough to withstand bumping and butting by livestock. Cages also could be used to prevent wildlife use as mentioned in item 2. An alternative to cages is to try to correct for the amount of vegetation used by grazing animals, though the techniques for this are imprecise and could introduce considerable bias into production estimates.

4. Animal Unit Conversion Values—A situation related to item 3 is where it may be necessary to convert technical standards given in animal units of grazing per unit area to weight of forage per unit area. Conversion values for different animal units and appropriate to the area usually can be obtained from State and Federal agricultural resource agencies. A conversion value of 20 pounds of air-dry forage per cow per day was used in Table 10 (page 49) to convert cow days of grazing per acre to pounds of forage per acre. The converted values represent herbage available for livestock under proper grazing management. Where sampled vegetation is clipped at ground level, a weight factor that adjusts for necessary nongrazed herbage should be subtracted from the clipped herbage or be added to the production standard. An alternative is to clip the vegetation at a height comparable to that for proper grazing.

5. Dry Weight—All production samples normally are converted to dry weights. For most situations, especially where reference areas are used for success standards, weight of the harvested vegetation usually is standardized by oven drying at 60° to 70°C. Where harvested vegetation is compared against technical standards, weights should be put on the same dry-weight basis as the standard. For hay, air-dry weights are most commonly recorded.

6. Time of Sampling—Where sampling is intended to reflect the peak or maximum productivity, sampling should be timed to coincide with the seed ripe or mature stage of the majority of the species in the plant community. Where a reference area is used it is logical to sample both it and the revegetated mine area at the same time, or time intervals, and when the majority of the species are at the highest level of production. The samples do not necessarily need to reflect the total year's growth or production of all species of the community, but they should be handled similarly on both areas.

There are numerous plant communities in which there is significant difference between the timing of flowering

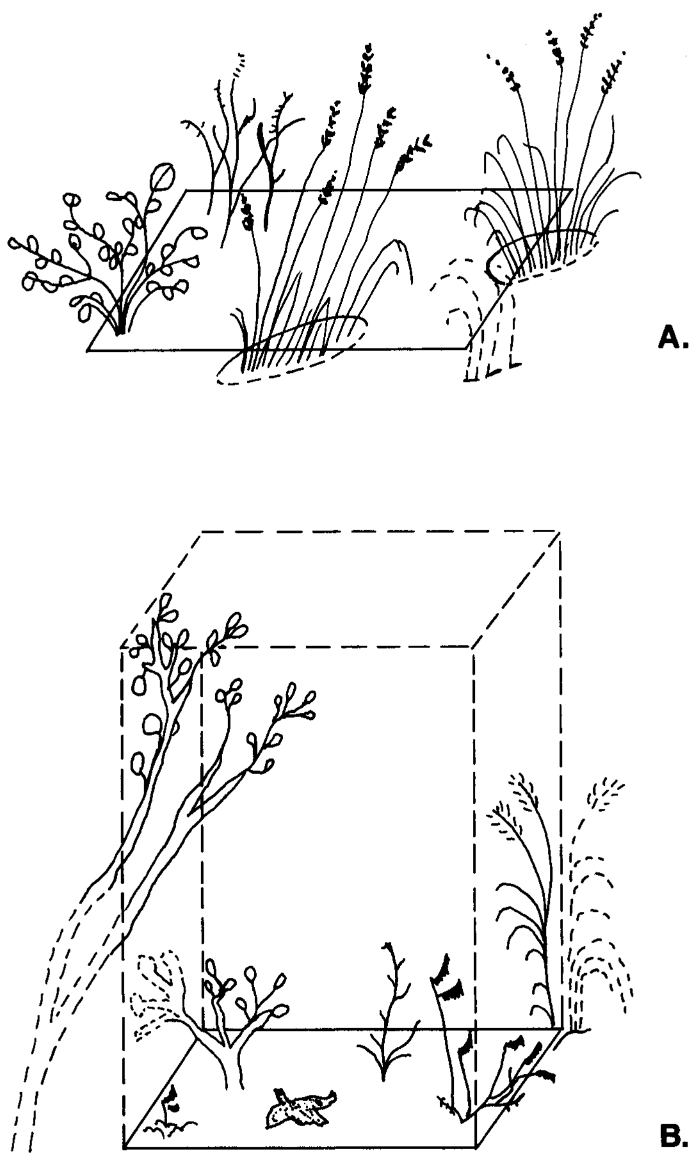


Figure 32. Clipping vegetation within quadrats as perceived by the (A) basal and (B) volume concepts.

and seed production of the major species. Two examples of this are communities with both cool-season (perennial ryegrass) and warm-season (little and big bluestem) grasses, and communities with grasses that flower and mature long before the shrubs. Cool-season plants generally make the major portion of their growth during the winter and early spring. Warm-season plants make most or all of their growth during the spring, summer, or fall, and usually are dormant in winter. In communities with varying seasonality, it may be necessary to sample when overall community production is at a peak. For the community with both cool-season and warm-season species, this would be at some point after the cool-season grasses have matured, but before they drop their seed. The warm-season grasses likely would be approaching maximum foliar growth and nearing the time of flowering. If the periods of peak production of the major species are extremely disparate, it may be desirable to sample at two different times to obtain an accurate estimate of total maximum productivity.

7. Quadrat Size and Shape—Selecting the proper plot size and shape is important for efficient sampling or sampling that will minimize both variance and sampling time. Van Dyne and others (1963) presented the following generalizations concerning the influence of plot size and shape:

- Perimeter-to-area ratios are lowest in circular plots and decrease as plot size increases. Low perimeter-to-area ratios generally decrease sampler error.
- More species generally are included in long, narrow plots.
- Optimum plot size and shape may depend on the distribution of the species measured, with larger plots usually recommended in sparse vegetation.
- Small sampling units, though generally more efficient statistically, often yield skewed data, and thus may not accurately represent the true population.

Both the type of vegetational community being sampled and the parameters being investigated will determine not only the plot size and shape but also the specific methodology to be used. Table 14 presents suggested quadrat sizes and shapes for use in several vegetation types.

8. Harvesting Cropland—For most crops, sampling to estimate production will not be necessary because production of the entire harvested crop can be determined. Where sampling is necessary, randomly placed quadrats or randomly selected rows or parts of rows can be used as sampling units. The crop would then be harvested from the sampling unit and processed in the normal manner for that crop. In sampling for hay production, a small sickle mower or a rotary lawn mower with bag catcher could be used to harvest the crop. Hand clippers and small quadrats also could be used. The cutting height should be the same as that normally used in mowing hay of that species in that locality. Because hay yields usually are on an air-dry basis, the harvested material should be air dried before it is weighed. The length and width (area) of the mowed quadrats should be known so that the yield from them can be converted to the same yield/area units as the standard.

Table 14. Quadrat sizes for sampling production with circular, square, or rectangular quadrat frames.

Vegetation Type	*Metric Measure (m^2)*	*English Measure (ft^2)*
Dense* tall-grass prairie and pastures	0.25–0.75	0.96–2.40
Sparse† tall-grass prairie and pastures	0.50–1.50	1.92–4.80
Woodlands-dense understory	0.75–1.50	2.40–4.80
Woodlands-sparse understory	1.00–2.50	4.80–9.60
Dense mid-grass prairie	0.25–0.75	0.96–2.40
Sparse mid-grass prairie	0.50–1.50	1.92–4.80
Dense shrublands	0.75–1.50	2.40–4.80
Sparse shrublands	1.50–2.50	4.80–9.60

*More than 50% aerial cover.
†Less than 50% aerial cover.

Quadrat Sizes and Conversions

To convert grams per quadrat to pounds per acre, multiply grams by the following conversion factors:

Quadrat area (ft^2)	*Conversion factor*
0.96	100
1.92	50
2.40	40
4.80	20
9.60	10

To convert grams per quadrat to kilograms per hectare, multiply grams by the following conversion factors:

Quadrat area(m^2)	*Conversion factor*
0.25	40
0.50	20
0.75	13.33
1.00	10
1.50	6.67
2.00	5
2.50	4

Kilograms per hectare × 0.89235 = pounds per acre
Pounds per acre x 1.12064 = kilograms per hectare

Double Sampling Methods

Double sampling using the weight-estimate method entails estimating vegetation production in the majority of the quadrats sampled and both estimating and harvesting production in a small percentage of the quadrats. This method allows the estimates of all quadrats sampled to be adjusted or corrected for estimator error by techniques, such as regression. This method lacks much of the precision and accuracy obtainable with the harvest method and generally is not recommended for making a final evaluation of production. Its use may be warranted for interim evaluations. This method can decrease the time and cost involved in sampling, but estimators require considerable training and must constantly check the accuracy of their own estimates if reasonably reliable data are to be obtained. Details on the use of this method are not given here, but can be obtained from numerous references on range measurement techniques, including some listed in the bibliography.

Measuring Stocking Success

Stocking as related to forestry can be defined in terms of volume, basal area, number of trees, crown closure, and other parameters. In relation to the revegetation of surface-mined lands, stocking normally means the number of individual trees and shrubs growing in a given unit area (also called density). Determining tree and shrub stocking is a matter of counting and recording the number of living plants in sample rows, plots, or quadrats, or on the entire inventory unit. This approach seems relatively simple but different sampling techniques may be needed for determining stocking of tree and shrub seedlings established from broadcast seeding compared to those spaced systematically in rows by hand or machine planting.

The most accurate way to measure stocking is to count the living trees and shrubs in an entire inventory unit. This would be too time consuming and costly for large areas, but may be the most expeditious method for evaluating small systematically spaced plantings of less than 2 acres, such as blocks and strips planted for wildlife habitat and shelterbelts. The procedure would be to simply walk the length of each row, count the number of living plants, and record them by species. The observer also may want to look for volunteer woody species and include them in the count. When the count is completed, divide the number of plants by the size of the area to determine the stocking or density. Information on plant distribution could be determined by noting their approximate location on a map or plat, or by keeping a running tally of living and dead or missing plants in each row. A knowledge of the original spacing of planted seedlings is helpful in determining the location of missing plants.

One of several sampling methods can be used to estimate stocking in large planted areas. Some methods for evaluating areas planted systematically in rows entail the random selection of several rows or portions of rows as sampling units. The plants counted in these rows or sampling units are then converted to number per unit area. Two procedures are described:

1. For planted units of uniform shape, such as square or rectangular, determine the area (acreage) and the total number of tree rows on that area by counting all rows or by estimating the number based on spacing between rows. Convert the percentage of sampling rows to acreage and calculate the number of living plants per acre from the number counted in the sampling rows. Example: an 18-acre rectangular area 1,600 feet in the long dimension would have 200 rows running across short dimension at an 8-foot spacing between rows. A sample consisting of 10 percent of the rows (20 rows) = 1.8 acres. If the total count of living trees in 20 rows is 840, then 840 divided by 1.8 acres = 467 trees/acre. Counts by rows would allow statistical testing for sampling adequacy and confidence limits.

2. A modified version of this procedure could be used on any large planted area, even an irregularly shaped area where row lengths are variable. Only the average spacing between rows of planted trees need be known or determined to compute stocking based on counts of living plants. The basic sampling unit is a section of row 209 feet long (an area measuring 209 by 209 feet equals 1 acre). Based on average spacing between rows of trees, the number of parallel rows that could be planted in a distance of 209 feet is the number of 209-foot row sections in 1 acre of area. Thus, the number of 209-foot row sections sampled can be converted directly to area and the number of plants counted expressed as number per acre. Example: the average spacing between rows on a inventory unit is 9 feet; thus, 209 divided by 9 = 23 row sections/acre. Assume 34 row sections (sample rows) counted with total of 446 living plants; 34 counted sections divided by 23 sections/acre = 1.48 acres sampled. Then, 446 total plants divided by 1.48 acres = 301 plants per acre.

Counting the number of tree and shrub plants within randomly placed sample plots or quadrats also can be used for determining stocking of systematically planted seedlings as well as for plantings that are not spaced systematically and those established from broadcast seedings. Quadrats large enough to include several planting spots are needed for evaluating systematically spaced plantings. These quadrats may be from 1/100 to 1/10 acre in size, but those that are 1/40 acre and smaller are easier to manipulate. To determine the number of trees or shrubs per acre, simply multiply the number counted in a quadrat by the denominator of the quadrat's size fraction, i.e., 40 in the case of a 1/40-acre quadrat.

For broadcast-seeded trees and shrubs and randomly planted seedlings (no systematic pattern), smaller quadrats (1/200 to 1/1,000 acre) are adequate to sample stocking. With small quadrats such as a milacre (1/1,000 of an acre), for example, simply recording the presence or absence of living stems gives an estimate of stocking and the distribution of plants. In fact, for forestry, this method of measuring stocking relates better to density of stocking in the future when stands are old enough to be evaluated by forest productivity parameters.

Quadrats for estimating stocking can be located within inventory units by one of the sampling designs described previously. Ground cover and stocking can be estimated at the same time. However, quadrats used for estimating stocking normally are too large to make reasonably accurate estimates of cover. A smaller quadrat, such as a square meter, or other device, such as a point-quadrat, could be placed at the same sampling point at which the larger quadrat for estimating stocking is located.

Quadrat shape has little effect on the accuracy of stocking measurements, especially in uniformly distributed vegetation. Circular quadrats probably are the most efficient shape for field use because a rope, wire, or stick of prescribed length can be used as the radius in circumscribing the plots. For example, a 1/100 acre circular plot has a radius of 11.7 feet; a milacre (1/1,000 acre) plot has a radius of 3.72 feet.

An alternate procedure may be convenient for estimating stocking in certain difficult conditions, such as on steep slopes. Here a rectangular plot or quadrat is used. The length of the plot could vary with the length of the slope and the width could be defined by a hand-held stick of a length that in relation to plot length provides a plot of known area. On a steep slope, for example, a rope tied to a tree or vehicle at the top of the slope would provide the long axis of the plot. Knots tied in the rope or marks painted on it would indicate the length of the plot, 33 feet, for example. A stick 6.6 feet long and held perpendicular to and centered over the rope (or on one side of it) by the observer delineates the width of a 1/200 acre plot as he or she descends or climbs the slope. The rope also provides the observer with something to hold to, if necessary, when climbing and descending the slope. The number of tree and shrub plants are counted within the boundary of the plot delineated by the stick and rope and multiplied by 200 to provide the number of plants per acre. A relatively narrow plot as illustrated here may give biased results if used in plantings spaced systematically.

Plant Community Structure and Species Diversity

Revegetation success can be evaluated and described by a variety of characteristics including those already discussed—cover, production, and stocking or density. Measuring and describing the structure and species diversity of plant communities also may be useful in judging the success or quality of revegetation, especially on native grassland and shrubland communities. Data for describing plant community structure and species diversity can be obtained in conjunction with the collection of cover, production, and density data.

Table 15. Comparison of Shannon's index, Spearman's R_0, and Sorenson's similarity index.*

Characteristic	*Shannon's Index H'*	*Spearman's R_0*	*Sorenson's Similarity Index*
Requires species or life form list	X	X	X
Requires measure of importance (production, cover, or density)	X	X	X
Requires same number of species or life forms in both areas		X	
Does not require same number of species or life forms in both areas	X		X
Tests apportionment of species or life forms between areas		X	X
Does not test apportionment of species or life forms between areas	X		
Independent diversity index for each area	X		
Diversity measure derived from comparison of both areas		X	X

*A discussion of the applicability of these methods along with illustrated examples is given in Chambers and Brown (1983). Application of the Shannon-Weiner Diversity Index to revegetated mined land is given by Larson (1980).

Community Structure Analysis

Community Structure Analysis is used to estimate the relative position of plant species within a community by calculating an importance value (IV) based on density, dominance, and frequency (Pase 1981). *Density* is the number of individuals per unit area. Actual counts of individuals of a species or class are needed per plot of known size. *Dominance* of a species can be expressed in several ways—size, basal area, or production of standing crop. From a practical standpoint, cover provides an easily measured characteristic that expresses the influence of one species on other community components, and on the site itself in terms of site utilization and protection from erosion.

Density and dominance values alone give no indication whether a species is well distributed over a site or occur only in infrequent (though possibly large) units. The number of plots or sample units on which a species occurs is termed *frequency*, and indicates how well a species is distributed on a site. For some species and some land uses, spacing of plants is more important than number of individuals or total cover.

The *importance value* for a species is a composite "score" that is determined from density, cover, and frequency values, and indicates the relative importance of that species in a plant community. The IV score tends to deemphasize the unique characteristics that may exaggerate the importance of any given species.

In practice, density, cover, and frequency data can be obtained in conjunction with the collection of cover, production, or stocking data by procedures and sampling systems described previously. Details on the application of the Community Structure Analysis method are found in Pase (1981) and Aldon (1984). A computerized program for analyzing data by this method is available from the latter.

Species Diversity

The concept of species diversity also provides an evaluation of the structure and composition of a plant community. The diversity concept contains two basic components, species richness (number of species in a defined area) and species evenness (proportionate distribution of individuals among species). Assessed together, these components are sometimes called "heterogeneity." Diversity usually is discussed in terms of species, but it also can be thought of in terms of life forms. In fact, the use of life forms in comparing the diversity of a reference area with that of a revegetated area may be more appropriate, especially where species different from those in the reference area are planted in the revegetated area.

Several methods of comparing the diversity of two areas are available to the investigator. These generally can be categorized as diversity indices, rank correlation tests, and similarity indices. Similarity indices probably provide the best available method for comparing reference and revegetated areas. Diversity and rank correlation indices have several shortcomings that make questionable their applicability for comparing reference and revegetated areas. The characteristics of three methods are compared in Table 15.

Statistical Procedures

Several of the references listed in the bibliography provide details on statistical procedures for determining adequacy of sampling (number of samples needed) and confidence limits and for comparing revegetated and reference areas. Also, most textbooks on statistical methods provide procedures for determining sampling errors, variances, regression, etc.

REVEGETATING COAL SURFACE-MINED LANDS IN THE EASTERN COAL REGIONS

The purpose of this chapter is to (1) briefly describe the coal regions in the eastern United States, (2) list and describe plant species suitable for revegetating surface-mined lands and criteria for selecting those species, and (3) suggest species and species mixtures for different uses of reclaimed land.

The coal and lignite regions in the eastern United States lie primarily east of the 100th meridian. They include the Appalachian Coal Region, the Interior Coal Region, and the Southern Lignite Region.

Appalachian Coal Region

The coal fields in the Appalachian Coal Region cover approximately 72,000 square miles in parts of nine states, extending from Pennsylvania to Alabama. For the purpose of this handbook, all of five states—Pennsylvania, Maryland, Ohio, West Virginia, and Virginia—and the eastern part of Kentucky are assigned to the Northern Appalachian Coal Region; three states—Tennessee, Georgia, and Alabama—are assigned to the Southern Appalachian Region (Figure 33). Eastern Kentucky, Virginia, and the southern third of West Virginia physiographically form the central part of the Appalachian Region and for revegetation purposes have commonality with both the Northern and Southern Appalachian Coal Regions.

Geology

The coals of the Appalachian Region are of Pennsylvanian Age, and are essentially coextensive with the Appalachian Plateau physiographic province. The most abundant coal-bearing rock types in Appalachia are the fine-grained siltstones and shales. Although less abundant, sandstones and conglomerates are conspicuous because of their resistant nature, frequently forming bold outcroppings and capping mountains. Limestone is prevalent in western Pennsylvania and Ohio, but in the rest of Appalachia, where present at all, lime is found mostly in calcareous shales or as a cementing agent in sandstones and siltstones. The coalbeds are distributed throughout the sequence of Pennsylvanian rocks.

Many of the coal-bearing strata contain varying amounts of the mineral pyrite, which is of considerable importance because of its potential for producing acid spoil and acid-mine drainage. However, with local exceptions, the patterns of acid-mine drainage affecting major stream systems indicate that this problem is most prevalent in Pennsylvania, portions of eastern Ohio, and a band along the boundary of Kentucky with West Virginia and Virginia in the Northern Appalachian Region and in north-central Tennessee in the Southern Appalachian Region. Coal-bearing strata that chemically are strongly alkaline are found in a few areas, but these strata are of minor consequence to the region.

Physiography

The Appalachian Coal Region occupies a high plateau that in most parts has been deeply incised by a dendritic stream pattern, giving rise to a rugged mountainous terrain. Altitudes range from 900 to 4,800 feet above sea level, with relief in the mountainous areas ranging from 500 to 1,500 feet. Slopes exceeding 30 degrees are common throughout much of the Appalachian region, with steeper slopes and vertical cliffs along major rivers. Terrain of this nature has necessitated contour and mountaintop-removal mining and has created severe erosion and stream sedimentation. In addition, transportation is hampered by the difficulty and expense of building and maintaining roads and railways.

Climate

Precipitation over all of the Appalachian Coal Region averages 47 inches annually. It ranges from 35 inches in Pennsylvania to a high of 55 inches in Alabama (Figure 34). The precipitation is fairly well distributed throughout the year, though any month could have the most or least precipitation in a given year. Approximately one-half of all precipitation is lost through evaporation and transpiration. Short periods of dry weather occur occasionally; longer periods occur infrequently, usually in late summer to early fall.

Average annual temperature ranges from about 50°F in Pennsylvania to a little over 60°F in Alabama. Average maximum temperature ranges from about 90° to 100°F, while average minimums range from around -10° to 10°F. Seasonal variations in temperature and precipitation are influenced to some extent by local topographic extremes. Some mountaintops and adjacent valleys may experience nearly as much climatic variation as occurs between the northern and southern parts of the region. However, largely because of its relative abundance overall, the variation in precipitation caused by topographic extremes is not great enough to produce extreme diversity in vegetation types. Average frost-free periods range from about 120 days in the north and high elevations in Maryland and West Virginia to 220 days in Alabama.

Native Vegetation

On the average, forest vegetation occupies about 80 percent of the land area being mined in the Appalachian Coal Region. The predominant forest type in the Northern Appalachian Coal Region is mixed hardwoods. Species composition ranges from almost pure northern red oak to pure yellow-poplar. However, the typical forest stand comprises a mixture of species. The most common species are northern red oak, yellow-poplar, sugar and red maples, white oak, American beech, white ash, American basswood, black cherry, cucumbertree, sweet and yellow birches, hickories, yellow buckeye, and black locust. Eastern hemlock and eastern white pine occur frequently in the mixture. Many other species occur occasionally.

Northern hardwoods are found in northern and eastern Pennsylvania and at higher elevations south into West Virginia. Sugar maple, American beech, and yellow birch are the predominant species in this type. Minor species include paper birch, white ash, red maple, eastern hemlock, balsam fir, and red spruce.

Along the eastern edge of the region, from southern Pennsylvania southward, the mixed hardwood type merges with an oak-pine type. Loblolly, shortleaf, and Virginia pines in mixture with northern red, white, scarlet, black, and chestnut oaks are the primary species in this type. Yellow-poplar and sweetgum are frequently associated with the oak-pine type.

The predominant forest type in much of the Southern Appalachian Coal Region is mixed hardwoods and is similar to and a continuation of the Northern Appalachian hardwood forest. However, species common to the Northern region, such as yellow birch, sugar maple, and American basswood, drop out of the mixed hardwood stands. Eastern hemlock and sweet birch occur less frequently and yellow-poplar and cucumbertree are more numerous. Species similar to those in the Northern Appalachian Region include northern red oak, white oak, white ash, red maple, black cherry, and hickories. Loblolly, shortleaf, and Virginia pines from the oak-pine type are common in the southern and eastern portions of the region.

A wide diversity of shrub species is associated with the forest types in this region. Some of the more common shrubs are dogwoods, viburnums, sumacs, cherries, hawthorns, elderberry, rhododendron, mountain laurel, alder, serviceberry, indigobush, chokeberry, redbud, witch-hazel, bayberry, and honeysuckle.

Cutting of merchantable timber without regard to forest management principles has been a continual process on much of the forested land since original settlement. Today, much of the private forest land is poorly managed or unmanaged and is stocked primarily with low-quality trees, both in species and in form. Nonforested lands are mainly those where the topography and soils have allowed the development of agricultural uses, primarily pasture.

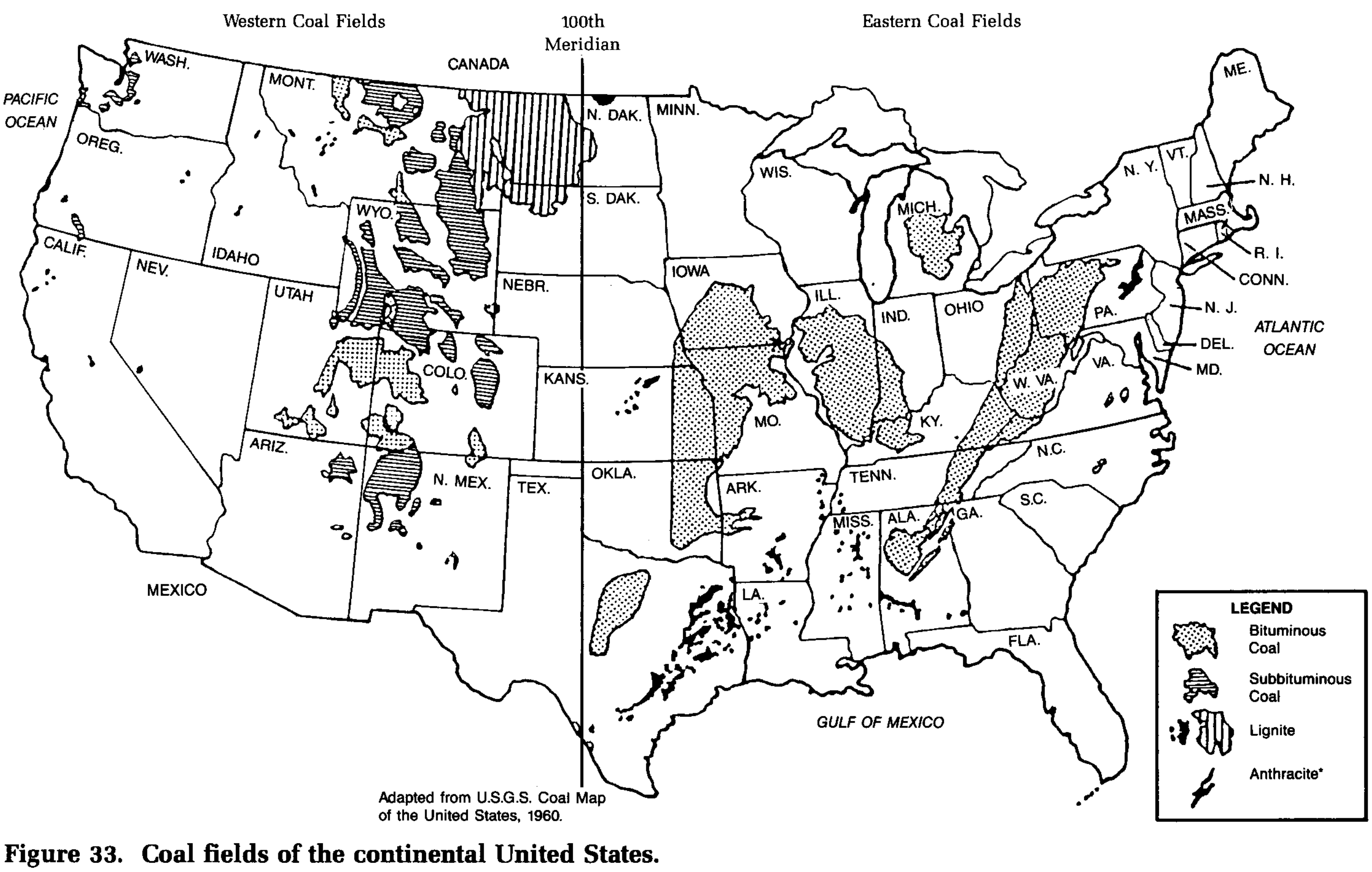


Figure 33. Coal fields of the continental United States.

Only in a few local areas does mining concide significantly with cropland uses.

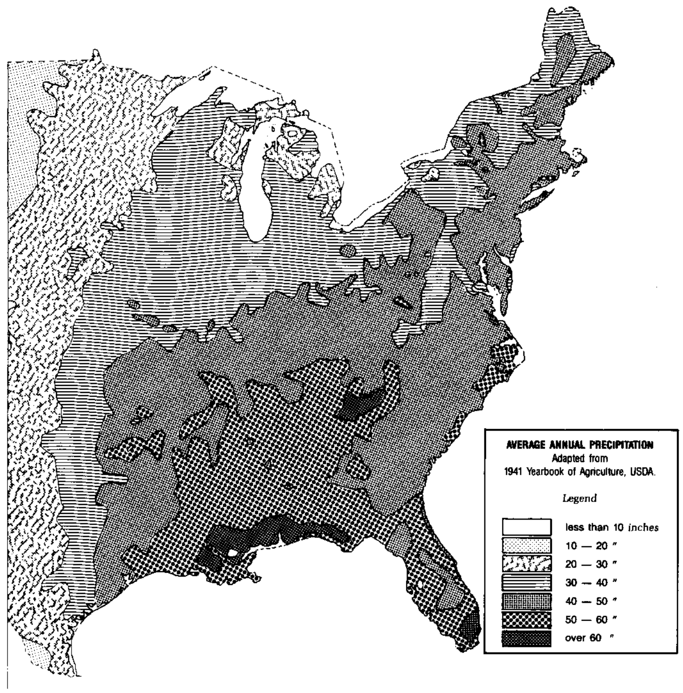


Figure 34. Precipitation zones of the eastern United States.

Interior Coal and Southern Lignite Region

The Interior Coal Region includes two major bituminous coal producing areas: the Eastern Interior and Western Interior Coal Regions. The Eastern Interior Region, also known as the Illinois Basin, lies primarily within Illinois, Indiana, and western Kentucky. The Western Interior Coal Region lies within Iowa, Missouri, Kansas, Oklahoma, and Arkansas. Bituminous coal deposits are found also in north-central Texas and along the Rio Grande in south-central Texas (Figure 33).

Lignite deposits are found in eastern Texas and portions of Arkansas, Louisiana, Mississippi, western Tennessee, and southwestern Alabama (Figure 33). Some of these lignite reserves are being mined, others are being developed for mining, or their potential for mining is uncertain. Much of the lignite mining in this region is relatively recent; thus, less information has been published on revegetating lignite mines than on revegetating bituminous mines in the Interior and Appalachian Regions. However, many of the same problems, practices, and recommendations apply to both types of mines.

Geology

The coals of the Interior Region are of Pennsylvanian age. As in Appalachia coal-bearing strata are predominantly shales, siltstones, and sandstones. However, in the Interior Region a repeating marine influence is more strongly seen; hence, limestones is not uncommon.

The marine influence is seen in the more abundant, highly pyritic black shales, especially in southern Illinois and western Kentucky in the Eastern Interior Coal Region. These shales cause problems with acid spoils and acid-mine drainage. In some areas, shallow underground mines, worked-out in the past, have been broken into by subsequent surface mining, releasing copious flows of extremely acid water, and damaging streams and nearby agricultural and forest lands subject to flooding. In other cases, surface mining has sealed or eliminated old underground mines, reducing the flow of acid water.

Minesoil toxicity resulting from acid-bearing strata is relatively minor for the Western Interior Coal Region as a whole, though it is serious in some localities. Similarly, problems with acid drainage from worked-out underground mines and with flooding of adjacent lands are less severe than in portions of the Eastern Interior Coal Region. The rock strata in the Western Region dip to the west-northwest; thus, the coal outcrops and coal mining are in the eastern part of the region.

The lignite deposits are primarily of Lower Tertiary age in association with sands and clays, some of marine influence.

Physiography

Most of the Eastern Interior Coal Region in Illinois and Indiana lies within the Central Lowlands physiographic province, while the portion in Kentucky and extreme southern Illinois and Indiana is in the Interior Low Plateaus. The boundary between these two physiographic provinces marks the southern limit of glaciation.

The Central Lowlands, in the vicinity of the coal fields, consists of broad, level uplands between steep-sided valleys with broad floodplains. This area is covered with glacial till and loess deposits that, toward the Mississippi River, reach 30 feet in thickness.

The Interior Low Plateaus consist of a slightly westward sloping plateau that is deeply entrenched with meandering rivers. This area has more relief than that to the north, but still is gently rolling. The low, gently rolling topography of the Eastern Interior Coal Region has allowed extensive area-type surface mining and an easily developed road, rail, and river barge transportation system.

The portion of the Western Interior Coal Region that lies north of the Missouri River is in the Dissected Till Plain section of the Central Lowland physiographic province. The southern part, lying in Kansas, Oklahoma, and southwestern Missouri, and the bituminous coal field in north-central Texas are in the Osage Plains, the small area extending into Arkansas falls within the Ouachita Province.

The Dissected Till Plain has been glaciated and, hence, is of low relief that ranges from 100 to 300 feet. The glacial till of this area is covered in the more eastern parts with up to 30 feet of loess.

The Osage Plains lies south of the glacial limit so it is of greater relief than the glaciated area of the Central Lowlands to the north. Most of the Osage area consists of upland plains with deeply entrenched rivers, some with valleys a few hundred feet deep.

The Ouachita Province resembles the Appalachian Mountains, but altitudes and relief are lower than in the Appalachians. Ridges in the Ouachita Mountains reach a maximum altitude of about 2,600 feet, about 1,500 feet above adjoining valleys.

The lignite deposits are primarily in the West Gulf and East Gulf sections of the Coastal Plain physiographic province. The relief in these sections can vary from nearly level to hilly, and elevations range from sea level to about 1,000 feet at the Balcones Escarpment.

Climate

Average annual precipitation in the Interior Coal Regions ranges from about 30 inches at the northern and western edges to about 50 inches at the eastern and southern boundaries (Figure 34). It may exceed 50 inches in portions of the East Gulf Coastal Plain and be as low as 20 inches in the western portion of the West Gulf Coastal Plain where lignite is found. Precipitation normally is greatest during the early-summer growing season, but droughts, especially in late summer, are not uncommon. Spring and summer rains often occur as severe thunderstorms with damaging winds, hail, and flooding. Temperatures are extreme and range from an average minimum of -20°F to average maximums of above 100°F.Average frost-free periods range from about 150 days at the northern edge to 300 days at the southern edge.

Native Vegetation

Several vegetation types are native to these coal regions. Tall grass prairie originally occupied a large portion of the Interior Regions, most of which has been converted to row crop and introduced pasture types of agriculture. Forested areas in the Interior Coal Region include the central hardwood type in the southeastern part and the oak-hickory type in the western part as well as in the bituminous coal area in north-central Texas. The Lignite Region crosses portions of the South Texas Plains, Post Oak Savannah (western fringe of the oak-hickory type), and east into the southern pine and oak-pine forest types.

The central hardwood type is a transition type from Appalachian hardwoods to oak-hickory. Common species are white and red oaks, red and sugar maples, yellow-poplar, American basswood, green and white ashes, black locust, and, on the best sites, black walnut. Cottonwood was a common volunteer species on prelaw surface-mine spoils.

The southern pine and oak-pine forest types are predominantly loblolly and shortleaf pines. Associated species are oaks, ashes, elms, hickories, and maples. Hardwoods are most common in bottomland sites. Most of the south Texas plains is rangeland with a large portion devoted to primary agriculture land.

Oak-hickory is the major forest type within the states of Iowa, Missouri, Oklahoma, and part of Texas. In addition to northern red, white, and black oaks, bur, post, blackjack, and pin oaks are common in the natural stands. Shagbark, pignut, mockernut, and bitternut hickories are common throughout the type. Associated species are ashes, elms, aspens, and black locust, and occasional black walnut on the better sites.

Criteria for Selecting and Establishing Plant Species

Reclamation success depends on successful establishment of vegetation, which, in turn depends on selection of species that are suitable for site and climatic conditions and postmining land uses. Criteria for selecting plant species include the type of plants, growth characteristics of those plants, adaptation to climate and site, type and availability of planting materials, and primary purpose or use for the species.

Types of Plants (Life Forms)

The plant species are classified into three types or life forms—herbs, trees, and shrubs. Each type has an important function in revegetation efforts, but all types may not be needed in the revegetation strategy for every land use.

Herbs

Herbs, or herbaceous plants, are nonwoody and are classified as grasses or forbs. *Grasses* belong to the Gramineae (grass) family. Most species have a fibrous root system that helps bind together soil particles and prevent erosion. *Forbs* are herbaceous plants other than those in the grass, sedge, and rush families. They generally are broad-leaved plants that have a tap-root or branching tap-root system. The forbs are further classified as *legumes* or *nonlegumes*. For vegetating mined lands, legumes most often are used and are especially valuable because they are nitrogen-fixing plants, i.e., by their symbiotic relationship with *Rhizobium* bacteria they convert atmospheric nitrogen into a form in the soil that is usable by plants.

The herbs (grasses and forbs) are especially beneficial for the quick establishment of vegetative cover for erosion control. Some herbaceous species also provide long-term site protection and are suitable for agricultural uses and for wildlife habitat.

Lifespan. The lifespan of herbaceous plants is either annual, biennial, or perennial, whereas trees and shrubs all are perennial (long-lived) species. A knowledge of the lifespan of these species can help reclamation managers select those best suited to the needs and objectives of the revegetation program.

Annual plants make vegetative growth, flower, produce seed, and die all within one season or one year. Annuals reproduce only from the seed they produce during this life cycle. Some annuals, such as Korean and Kobe lespedeza, usually regenerate (volunteer) a stand each year from the seed they produce, but other annuals such as rye and millet cannot be depended on to volunteer satisfactory stands. Annuals usually are the best species to plant for the quick establishment of a vegetative cover.

Biennial plants live for only two growing seasons. Biennials such as yellow sweet clover produce most of their vegetative growth in the year they are sown. In the second year they produce vegetative growth early in the season, then flower, produce seed, and die. Few of the species listed are biennial.

Most *perennial* plants live at least 3 years and usually longer. Herbaceous perennials die back to the ground each year but regenerate new growth from roots or crowns.

They also reproduce from seed. Plants of a few perennials such as perennial ryegrass are relatively short-lived (2 to 4 years), but most perennial plants have a longer, usually indefinite, lifespan.

Season of Major Growth. A knowledge of when herbaceous plants grow is helpful in determining how and when species can be used best in the revegetation scheme. The growth period of herbaceous plants is grouped into two major seasons—cool and warm. Trees and shrubs also may have a season of major growth, but this usually has little influence on when they would be planted.

Cool-season species grow mostly in the spring and fall and usually are dormant, semidormant, or grow slowly in the summer. These plants usually are dormant in winter though in warmer regions, some cool-season species may continue to grow during the winter. Cool-season species usually are established most easily by seeding in the spring or late summer to early fall. A few species, such as alfalfa, crownvetch, and birdsfoot trefoil, continue to grow during the summer but usually are sown in the spring or fall and are classified as cool-season plants in this handbook.

Some cool-season plants are called winter annuals. They normally are sown in the fall. After the seeds germinate, the plants make some growth before going dormant or semidormant over winter. These plants resume growth in the early spring, produce seed in late spring or early summer, and then die. Most winter annuals also produce cover when sown in the spring. Rye, winter wheat, annual ryegrass, and hairy vetch are examples.

Warm-season species grow mostly during the late spring and summer and are dormant in early spring, fall, and winter. Warm-season species usually are sown in the spring. Summer annuals, such as foxtail millet and sorghum, normally are sown in late spring and early summer and are especially useful for the quick establishment of vegetative cover. Summer annual species complete their life cycle during late summer and early fall. Both summer and winter annuals can be grown to produce mulch in place.

Shrubs

Shrubs are plants with few to many persistent woody stems arising from the ground and without definite crown shape. Shrubs usually are smaller than trees, though in other literature some large shrubs may be classified as trees. Most of the species listed as shrubs herein do not exceed a height of 20 feet at maturity. Shrubs usually do not provide good erosion control in the early stages of growth, but within a few years will provide site protection and can be used for screening. They are especially valuable for providing food and cover for wildlife. Some shrubs are nitrogen-fixers. Some of these are legumes that fix nitrogen through association with *Rhizobium* bacteria; others, such as autumn olive and black alder, host a different kind of nitrogen-fixing microbial associate.

Trees

Trees are large woody plants that generally have a single stem and a definitive crown shape. They are classified as *conifers* (cone bearers) or *hardwoods*. Most conifers belong to the pine family and are evergreen (three of the listed conifers are deciduous). Hardwoods belong to plant families other than pine and most are deciduous, i.e., their leaves are dropped annually.

Trees are not effective for controlling erosion in the early stages of life, but as the tree canopy closes and litter accumulates they provide long-term or permanent cover and site protection. Given sufficient time, some trees produce wood or timber products of commercial value. Many species provide food and cover for wildlife. A few tree species are nitrogen-fixers. Because they can improve soil conditions, these nitrogen-fixers may serve as "nurse" species where interplanted with other tree species.

Tree Size. The relative height of a mature tree growing in its natural range and on natural soils is classified and defined as *small*— 20 to 40 feet; *medium*— 40 to 90 feet; *large*— 90 to 150 feet. A knowledge of tree size may be useful in selecting trees for screening or landscaping purposes, and to help envision the future appearance of a forest plantation.

Shade Tolerance. Shade tolerance is the term commonly used to express the capacity of a tree or shrub to develop and grow in the shade of other trees. Although oversimplified, shade tolerance for the purpose of this handbook is categorized and defined as: *tolerant*— trees can tolerate or withstand fully shaded conditions (low light intensity) for long periods of time; *intolerant*— trees cannot tolerate shaded conditions (require relatively high light intensity); *intermediate tolerance*— trees can tolerate partial shading or can tolerate full shade for short periods.

A knowledge of the shade tolerance of a species may seem unimportant in vegetating a newly mined site. Often, however, several species of trees and shrubs are planted together or plantings may be staggered over a period of several years. As plant growth progresses, some species overtop and shade others. Some species are adversely affected by shading but others are not. For example, hardwoods, where interplanted with intolerant species of pine, often overtop, shade, and cause the slower growing pine to lose vigor and eventually die. Conversely, species tolerant of shade such as spruce may initially grow slowly in the shade of larger or faster growing plants, but eventually will equal or emerge above them.

Origin

Species are identified as either *native* or *introduced*. Many of the introduced species are naturalized and, like the native species, will persist without cultivation. A knowledge of species origin may be useful to reclamation managers because the use of native species is a requisite for some postmining land uses and is an alternative to using introduced species for other land uses.

Regions Where Adapted

The species described later in this chapter are recommended for the appropriate coal region(s) or part of them. In some cases, these species may grow satisfactorily in more of the region than indicated, but their use on mined lands in all parts of the region has not been documented. The region or parts of it coincide fairly closely with the natural range of most of the recommended native tree and shrub species.

A few species have been used successfully beyond their natural range. For example, the natural range of red pine and jack pine is the northernmost part of the United States and adjacent southern Canada. Yet, these pine have been used far south of this range.

The probability of long life or permanence of a species usually is greater where planted in or near its natural range (or environment similar to its natural one in case of an introduced species) than outside its natural range. Planted outside their natural range, some species or some plantings of a species may succumb to extremes in weather, fail to regenerate, or be susceptible to disease and insect pests that usually are not a problem in their natural range.

Elevation Limit

Plants usually grow best in the climatic range in which they are adapted. Topographic elevation influences climate and so can affect the establishment and growth of plants. For example, most of the Northern Appalachian Region is in the natural range of Virginia pine. But this tree does not grow well above 2,500 feet, especially in the northern half of the Appalachians. Similarly, a warm-climate forb, such as sericea lespedeza, may germinate and grow at the lower elevations in northern West Virginia, but winter temperatures at the higher elevations may be too severe for the success of that species. Most of the Southern Appalachian Region is in the natural range of loblolly pine, but this tree does not grow well or may suffer winter damage at higher elevations in the northern part of this region. Limits are shown for species where elevation is known or suspected to be a factor hindering their establishment.

Lower pH Limit

Acidity (low pH) is a major factor limiting the establishment of vegetation on some of the mined lands in the East. Knowing the acidity tolerance of a species can be helpful in selecting those most suitable for vegetating acid minesoils. However, selecting plants for acid tolerance may be less important now than in the past due to changing practices in mining and reclamation, such as segregation and planned placement of overburden strata, replacement of native soil, and amendment of acid soils. Alkalinity or high pH seldom causes revegetation problems in the eastern coal regions; thus, upper limits of pH tolerance are not given. However, pH of overburden materials in some areas, such as the Warrior Basin of Alabama, are high enough to cause problems with species such as pine that grow best in acid soils. The upper limit for good growth of most plants is about pH 8.0. For pine trees, the upper limit is somewhat lower (6.5).

Planting Materials

The type of plant materials used to establish the species are identified in the plant descriptions that follow. With few exceptions, trees and shrubs are most often established by planting nursery-grown seedlings. The age of nursery seedlings recommended for planting on mined lands is shown in parentheses. However, seedlings of the same age are not always the same size; thus, the buyer must be sure that the seedlings are of the proper size for planting. Hybrid poplars, willow, and sometimes cottonwood can be established by planting either rooted or unrooted cuttings.

A few of the woody species can be established by direct seeding. Treatment of the seed is recommended for some species. The herbaceous species generally are established from seed. Crowns, sprigs, and sod are used to a limited extent for establishing a few species. Most cultivars of Bermudagrass must be planted vegetatively (by sprigging). Seed of herbaceous legumes and some of the shrubby legumes should be inoculated with the appropriate *Rhizobium* bacteria. Wide-spectrum or standard inoculants are available commercially for most of the commonly used legumes. Species that require specially prepared inoculum are identified.

Insofar as possible, attention should be given to seed source for all species planted, but especially for tree species. In general, when reforesting an area, it is best to use local seed sources because they have a better chance than outside seed sources of being adapted to the local environment. See the chapter on *Vegetation Establishment and Cultural Practices* for a discussion and recommendations on size of planting stock, spacing of seedlings, time of planting, direct seeding, inoculation of legume seed, and seed sources.

Seeding Rate

Rates of seeding are recommended for herbaceous species and for tree and shrub species that can be direct seeded. The rates are given as pounds per acre of *pure live seed* (PLS). For some species, a range in rates is suggested both for use in mixtures and, where advisable, for seeding alone. The higher rates should be used where environmental conditions are least favorable for seedling establishment, such as on poorly prepared seedbeds and steep slopes. Seeds of some species are susceptible to damage when sown with a hydroseeder; thus, using the higher rates helps compensate for the damaged seeds. The lower seeding rates are suggested for well-prepared seedbeds and especially where seed is planted with drill seeders. Special directions are given for tree species that can be established from planting of nuts. A discussion of seeding rates and an explanation of pure live seed are given in the chapter on *Vegetation Establishment and Cultural Practices.*

Time of Seeding

The season or seasons of the year is indicated when a species normally is seeded. Additional information on time of seeding is discussed in the chapter on *Vegetation Establishment and Cultural Practices.*

Superior Cultivars

Varieties, strains, or selections that have one or more superior qualities are listed for some species. When available, the use of superior cultivars usually is recommended over unimproved cultivars. Exceptions may be where the postmining land use is wildlife habitat or forestry. Consult agricultural agencies such as your State Extension Service or the USDA Soil Conservation Service for advice on recommended cultivars for agricultural uses in your locality.

Rate of Establishment

This qualitative rating is the length of time usually required for a herbaceous species to become established and develop sufficient foliage to cover 70 percent or more of the ground surface. The rates are: *Rapid*— the desired cover is established within the first growing season after seeding (for fall-sown species, this includes the fall plus the next spring growing periods); *Moderate*— requires more than one growing season to establish the desired cover, but may not require a full second growing season; *Slow*— requires more than two full growing seasons to establish the desired cover.

These criteria apply primarily to a species when sown alone; the rate of establishment could vary when the species is sown in mixtures. These criteria also assume that (1) seeding is done in the appropriate season for that species; (2) seed was sown on mechanically prepared or frost-loosened seedbeds on minesoils that have been limed and fertilized properly; and (3) the minesoils do not have other chemical or physical properties that would hinder usual seed germination and plant development.

Major Uses

Major uses of species planted on mined lands are listed in the plant descriptions. Erosion control and watershed protection are provided by nearly all plants at some stage of development. However, these uses are not listed for most of the tree and shrub species because these plants usually provide little site protection during the first few years after planting. Conversely, many of the herbaceous species provide rapid cover and are especially important for erosion control and watershed protection. Nearly all species contribute to esthetics; for a few species, esthetics and screening can be major uses. Forest products are a potential long-range use for many of the tree species listed.

Comments

This item includes other factors of interest or importance, and data on growth performance of some of the tree species. Much of the tree-growth data was gathered in a recent survey of 30-year-old experimental plantings throughout the eastern coal regions. Data on tree performance are averaged from a number of test sites in the States indicated and include percent survival, average diameter at breast height (dbh), average height, and basal area (an indicator of stand density). Most of the basal-area values were calculated by multiplying the number of surviving trees per acre (determined from percent survival) by the mean cross-sectional areas of the trees (determined from average dbh). Trees in the experimental plantings were on a 7- by 7-foot spacing (890 trees per acre).

Plant Species for Revegetation

Plant species that have been used and are recommended in revegetating coal surface-mined lands in the Eastern Coal Regions are identified and described in this chapter. Both common and scientific (Latin) names are listed to clarify species identification (Table 16). This list does not include all the plant species that will grow on reclaimed surface-mined lands. A few species that were successful in experimental plantings are not listed because they are unsuited or have little value for most land uses. Many species besides those listed volunteer on mined land, but some of them have not been successful where artificially planted. Others have not been artificially planted because planting stock or seed has not been commercially available. Also, use of some of the listed species may be limited at times when planting stock or seed are in short supply or are unavailable.

Several of the listed species have been grown successfully in experimental plantings but have not been used, or are seldom used, in large-scale or commercial plantings. In fact, on the majority of successfully reclaimed surface mines, revegetation has been accomplished with the use of relatively few plant species. Greater use could be made of many of the listed species—some for commercial forestry and agricultural uses, and others for increasing vegetative diversity for wildlife habitat and for restoring vegetational types similar to those that existed before mining. Where the native surface soils are being replaced it is reasonable to assume that most of the species growing naturally on such soils could be reestablished. However, due to compaction and changes in soil structure and possibly other characteristics, some of these species may not be easily reestablished immediately. Least risk probably is incurred by using species that have tested successfully on reclaimed mines.

Some of the plant species described in this chapter are suitable for use in all of the Eastern Coal Regions, however, most species are adapted or suited to one region or part of a region better than they are to other regions or parts of a region.

Species Descriptions

The descriptions that follow have been prepared for species that are used and recommended most frequently, and for some that have proven successful in experimental plantings but otherwise may have been little used. For species of lesser importance, and those that are seldom used, similar but less detailed information is given in Tables 17-20. The species descriptions are arranged by plant type in the order: grasses, forbs, shrubs, and trees.

Table 16. Plant species for revegetating coal surface-mined lands in the Eastern Coal Regions. Detailed information on species in bold face type is given on individual descriptions in the following pages. The other species are described briefly in Tables 17–20.

Common name	Scientific Name and Authority*
GRASSES	
Bahiagrass	*Paspalum notatum* Flugge
Highland bentgrass	*Agrostis tenuis* Sibth.
Bermudagrass	*Cynodon dactylon* (L.) Pers.
Canada bluegrass	*Poa compressa* L.
Kentucky bluegrass	*Poa pratensis* L.
Big bluestem	*Andropogon gerardi* Vitm.
Caucasian bluestem	*Bothriochloa caucasica* (Trin.) C.E. Hubb
King ranch bluestem	*Bothriochloa ischaemum* va. *Songarica* (Rup. ex Fisch. & Mey.) Celar. & Harlan
Little bluestem	*Schizachyrium scoparium* (Michx.) Nash
Smooth brome	*Bromus inermis* Leyss.
Buffalograss	*Buchloe dactyloides* (Nutt.) Engelm.
Reed canarygrass	*Phalaris arundinacea* L.
Corn	*Zea mays*
Dallis grass	*Paspalum dilatatum* Poir.
Deertongue	*Panicum clandestinum* L.
Red fescue	*Festuca rubra* L.
Tall fescue 'Kentucky-31'	*Festuca arundinacea* Schreb., selection Ky-31
Sideoats grama	*Bouteloua curtipendula* (Michx.) Torr.
Indiangrass	*Sorghastrum nutans* (L.) Nash
Weeping lovegrass	*Eragrostis curvula* (Schrad.) Nees
Browntop millet	*Brachiaria ramosa* (L.) Stapf
Foxtail millet	*Setaria italica* (L.) Beauv.
Japanese millet	*Echinochloa crusgalli* var. *frumentacea* (Link) W.F. Wight
Pearl millet	*Pennisetum americanum* (L.) Leeke
Tall oatgrass	*Arrhenatherum elatius* (L.) Beauv. ex J. & C. Presl
Oats	*Avena sativa* L.
Orchardgrass	*Dactylis glomerata* L.
Redtop	*Agrostis gigantea* Roth
Rye	*Secale cereale* L.
Annual ryegrass	*Lolium multiflorum* Lam.
Perennial ryegrass	*Lolium perenne* L.
Sorghum	*Sorghum bicolor* (L.) Moench
Sudangrass	*Sorghum sudanense* (Piper) Stapf
Switchgrass	*Panicum virgatum* L.
Timothy	*Phleum pratense* L.
Western wheatgrass	*Agropyron smithii* Rydb.
Winter wheat	*Triticum aestivum* L.

Common name	Scientific Name and Authority*
FORBS-LEGUMES	
Alfalfa	*Medicago sativa* L.
Illinois bundleflower	*Desmanthus illinoensis* (Michx.) MacMill.
Alsike clover	*Trifolium hybridum* L.
Arrowleaf clover	*Trifolium vesiculosum* Savi.
Crimson clover	*Trifolium incarnatum* L.
Kura clover	*Trifolium ambiguum* Bieb.
Ladino clover	*Trifolium repens* L.
Red clover	*Trifolium pratense* L.
Subterranean clover	*Trifolium subterraneum* L.
White clover	*Trifolium repens* L.
Cowpea, Black-eyed pea	*Vigna unguiculata* (L.) Walp. subsp. unguiculata
Crownvetch	*Coronilla varia* L.
Flatpea	*Lathyrus sylvestris* L.
Common lespedeza	*Lespedeza striata* (Thunb. ex Murr.) Hook. & Arn.
Kobe lespedeza	*Lespedeza striata* var. Kobe
Korean lespedeza	*Lespedeza stipulacea* Maxim.
Prostrate lespedeza	*Lespedeza daurica* var. *schimadai* Matsamune
Sericea lespedeza	*Lespedeza cuneata* (Dum.) G. Don
Cicer milkvetch	*Astragalus cicer* L.
Partridge pea	*Cassia fasciculata* Michx.
Purple prairie clover	*Petalostemum purpureum* (Venten.) Rydb.
Soybean	*Glycine max* (L.) Merr.
White sweetclover	*Melilotus alba* Medik.
Yellow sweetclover	*Melilotus officinalis* Lam.
Birdsfoot trefoil	*Lotus corniculatus* L.
Bigflower vetch	*Vicia grandiflora* Scop.
Hairy vetch	*Vicia villosa* Roth
FORBS-NONLEGUMES	
Buckwheat	*Fagopyrum esculentum* Moench
Japanese fleeceflower	*Polygonum cuspidatum* Sieb. & Zucc.
'Eureka' Thickspike gayfeather	*Liatris pycnostachya* Michx.
'Sunglow' Grayhead prairie coneflower	*Ratibida columnifera* (Nutt.) Woot. and Standl. var.
'Nekan' Pitcher sage	*Salvia azurea* var. grandiflora Benth.
Common sunflower	*Helianthus annuus* L.
Maximilian sunflower	*Helianthus maximiliani* Schrad.

*Names and authorities mostly follow Terrell 1977 and Little 1979. Another source is L.H. Bailey Hortorium 1976.

Table 16. Plant species for revegetating coal surface-mined lands in the Eastern Coal Regions. Detailed information on species in bold face type is given on individual descriptions in the following pages. The other species are described briefly in Tables 17–20.

Common name	*Scientific Name and Authority**	*Common name*	*Scientific Name and Authority**
SHRUBS		TREES—HARDWOODS	
Blueberry	*Vaccinium* L. Spp.	**European black alder**	*Alnus glutinosa* (L.) Gaertn.
Silver buffaloberry	*Shepherdia argentea* (Pursh) Nutt.	**Crab apple**	*Malus* Mill. spp.
Chokecherry	*Prunus virginiana* L.	**Green ash**	*Fraxinus pennsylvanica* Marsh.
Gray dogwood	*Cornus racemosa* Lam.	**White ash**	*Fraxinus americana* L.
Red-osier dogwood	*Cornus stolonifera* Michx.	Bigtooth aspen	*Populus grandidentata* Michx.
Silky dogwood	*Cornus amomum* Mill.	European white birch	*Betula pendula* Roth
American elder	*Sambucus canadensis* L.	Gray birch	*Betula populifolia* Marsh.
Grape	*Vitis* L. Spp.	Paper birch	*Betula papyrifera* Marsh.
Hawthorn	*Crataegus* L. spp.	**River birch**	*Betula nigra* L.
Amur honeysuckle	*Lonicera maackii* (Rupr.) Maxim.	Sweet birch	*Betula lenta* L.
Japanese honeysuckle	*Lonicera japonica* Thunb.	Catalpa	*Catalpa* Scop. spp.
Morrow honeysuckle	*Lonicera morrowii* A. Gray	**Black cherry**	*Prunus serotina* Ehrh.
Tatarian honeysuckle	*Lonicera tatarica* L.	**Chinese chestnut**	*Castanea mollissima* Blume
Indigobush	*Amorpha fruticosa* L.	**Eastern cottonwood**	*Populus deltoides* Bartr. ex Marsh.
Japan lespedeza	*Lespedeza japonica* L. H. Bailey	Flowering dogwood	*Cornus florida* L.
Shrub lespedeza	*Lespedeza bicolor* Turcz.	Hackberry	*Celtis occidentalis* L.
Thunberg lespedeza	*Lespedeza thunbergii* (DC.) Nakai	Hickory	*Carya* Nutt. spp.
Bristly locust	*Robinia fertilis* Ashe	**Black locust**	*Robinia pseudoacacia* L.
Rose-acacia locust	*Robinia hispida* L.	**Red maple**	*Acer rubrum* L.
Autumn olive	*Elaeagnus umbellata* Thunb.	**Silver maple**	*Acer saccharinum* L.
Amur privet	*Ligustrum amurense* Carr.	**Sugar maple**	*Acer saccharum* Marsh.
American plum	*Prunus americana* Marsh.	Red mulberry	*Morus rubra* L.
Rugosa rose	*Rosa rugosa* Thunb.	**Bur oak**	*Quercus macrocarpa* Michx.
Western sandcherry	*Prunus besseyi* L. H. Bailey	Chestnut oak	*Quercus prinus* L.
Fragrant sumac	*Rhus aromatica* Ait.	**Northern red oak**	*Quercus rubra* L.
Shining sumac	*Rhus copallina* L.	Pin oak	*Quercus palustris* Muenchh.
Viburnum	*Viburnum* L. Spp.	**Sawtooth oak**	*Quercus acutissima* Carruth.
Purple osier willow	*Salix purpurea* L.	Shingle oak	*Quercus imbricaria* Michx.
		White oak	*Quercus alba* L.
TREES—CONIFERS		Other oaks	*Quercus* spp.
		Russian olive	*Elaeagnus angustifolia* L.
Baldcypress	*Taxodium distichum* (L.) L. Rich.	**Osage orange**	*Maclura pomifera* (Raf.) Schneid.
Douglas fir	*Pseudotsuga Carr. spp.*	Royal paulownia	*Paulownia tomentosa* (Thunb.) Steud.
Fraser fir	*Abies Fraseri* Pursh.	Pecan	*Carya illinoensis* (Wangenh.) K. Koch
European larch	*Larix decidua* Mill.		
Japanese larch	*Larix leptolepis* (Sieb. & Zucc.) Gord.	**Hybrid poplar**	*Populus* L. spp.
		Yellow-poplar	*Liriodendron tulipifera* L.
Austrian pine	*Pinus nigra Arnold*	**Sweetgum**	*Liquidambar styraciflua* L.
Eastern white pine	*Pinus strobus* L.	**American sycamore**	*Platanus occidentalis* L.
Jack pine	*Pinus banksiana* Lamb.	**Black walnut**	*Juglans nigra* L.
Loblolly pine	*Pinus taeda* L.	Black willow	*Salix nigra* Marsh.
Longleaf pine	*Pinus palustria* Mill.		
Pitch pine	*Pinus rigida* Mill.		
Pitch X loblolly hybrid pine	*Pinus* X *rigitaeda* (*rigida* X *taeda*)		
Red pine	*Pinus resinosa* Ait.		
Scotch pine	*Pinus sylvestris* L.		
Shortleaf pine	*Pinus echinata* Mill.		
Slash pine	*Pinus elliottii* Engelm.		
Virginia pine	*Pinus virginiana* Mill.		
Eastern redcedar	*Juniperus virginiana* L.		
Norway spruce	*Picea abies* (L.) Karst		
White spruce	*Picea glauca* (Moench) Voss		

*Names and authorities mostly follow Terrell 1977 and Little 1979. Another source is L. H. Bailey Hortorium 1976.

BERMUDAGRASS
(*Cynodon dactylon*)

Type of plant: Grass

Origin: Introduced

Lifespan: Perennial

Season of major growth: Warm

Lower pH limit: 3.5 to 4.0

Elevation limit: Avoid higher elevations in Appalachian Region

Planting materials: Sprigs; seed (common Bermuda only)

Seeding rate: 3 to 5 lb/acre in mixtures, 7 to 12 lb/acre alone

Sprig spacing: 2 to 3 feet apart in rows 3 to 4 feet apart (4,000 to 6,000 sprigs/acre) or 20 to 35 bu/acre broadcast.

Time of seeding: Spring after mean daily temperatures exceed 65°F.

Time of sprigging: Any month; spring and summer best

Superior cultivars: Midland, Coastal, Tifton 44, Quicksand common, Hardy, 'Tufcote'

Rate of establishment: Rapid

Major uses: Erosion control (quick, short-to-long-term cover); forage

Regions where adapted: Southern Appalachian, southern part of Interior, Southern Lignite

Comments: This semitropical grass grows best on moist, heavy-textured soils in hot weather, but tolerates a wide range of minesoil conditions, including extremely acid, salty, and drouthy conditions. Common Bermuda can be established from seed, but commercial sources usually are not winter-hardy in the northern parts of the Coal Regions. Superior cultivars including the more winter-hardy ones (Midland, Hardy, Tifton 44, Quicksand common) are established by planting sprigs. Quicksand common is a recent selection that may survive winters in the southern half of Illinois and eastward through most of the Appalachian Region. This cultivar also is more productive in soil of low fertility, establishes more rapidly, initiates growth at cooler temperatures, and is more drought-tolerant than the other cultivars listed. 'Tufcote' is a cultivar reported to grow in spoils with pH as low as 3.2. Bermudagrass is a highly productive and valuable forage species in southern areas when management and soil fertility are maintained at high levels. Plants spread quickly by rhizomes and stolons and provide good ground cover.

BIG BLUESTEM
(*Andropogon gerardi*)

LITTLE BLUESTEM
(*Schizachyrium scoparium*)

Type of plant: Grass

Origin: Native

Lifespan: Perennial

Season of major growth: Warm

Lower pH limit: 4.5

Planting materials: Seed

Seeding rate: 4 to 8 lb/acre in mixture, 8 to 15 lb/acre alone

Time of seeding: Spring

Superior cultivars: "Kaw" big bluestem, "Aldous" and "Blaze" little bluestem

Rate of establishment: Slow to moderate

Major uses: Watershed protection (long-term cover), forage, wildlife habitat, esthetics

Regions where adapted: All

Comments: Bluestems are native to all Eastern States and are important components of tall grass prairie. Seeded stands may be slow to develop full cover, but once established, the stands require little maintenance. Big bluestem may reach 6 to 7 feet tall; little bluestem 3 to 4 feet. Usually sown in mixture with other native grass and forbs species. Include a light seeding of oats or rye to provide initial cover, or seed the native grasses into residue of a summer annual crop grown the year before. Unprocessed seeds are light and fluffy and can be difficult to drill or broadcast. Processing seed to remove fluffy appendages shortens the period of seed viability. Germination and purity of seed may be low, so be sure seeding rates are based on PLS values. Bluestems are valuable summer forage for livestock and provide cover for game birds and small mammals. When herbage is not used, occasional removal of heavy litter buildup will help maintain vigorous plant growth. Where land uses permit, heavy litter can be removed by burning. The superior cultivars listed are adapted to most parts of all regions, but check for locally recommended cultivars, especially in western and southwestern parts of Interior Region.

SMOOTH BROME
(Bromus inermis)

Type of plant: Grass

Origin: Introduced

Lifespan: Perennial

Season of major growth: Cool

Lower pH limit: 5.5

Planting materials: Seed

Seeding rate: 10 to 15 lb/acre in mixture, 20 to 25 lb/acre alone

Time of seeding: Spring, late summer-early fall

Superior cultivars: Consult local agricultural agencies for recommendations

Rate of establishment: Moderate to slow

Major uses: Forage, erosion control (long-term cover and waterways)

Regions where adapted: northern Appalachian, northern half of Interior

Comments: This sod-forming grass is best adapted to the northern regions. Not recommended in Kentucky, Virginia, and further south. Smooth bromegrass is a leafy, palatable forage plant and often is sown with a legume such as alfalfa. Where established alone it produces a dense sod that provides good erosion control in areas such as grassed waterways that are subject to overland flows. Old stands develop nitrogen deficiency and require fertilization for maintenance. Selection of appropriate seed sources and varieties is important for northern versus southern latitudes. Consult local agricultural authorities for recommendations on the variety or type suited for a given area.

REED CANARYGRASS
(Phalaris arundinacea)

Type of plant: Grass

Origin: Introduced

Lifespan: Perennial

Season of major growth: Cool

Lower pH limit: 4.5

Planting materials: Seed; sprigs

Seeding rate: 5 to 8 lb/acre in mixture, 8 to 12 lb/acre alone

Time of seeding: Spring, late summer

Rate of establishment: Moderate

Major uses: Erosion control, wildlife habitat

Regions where adapted: Interior and Northern Appalachian

Comments: Adapted over most of the Interior Coal Province but thrives especially in the northern half. It is recommended primarily for moist or wet sites, such as pond shorelines, drainage ditches, grassed waterways, and stream channel banks. This sod-former can be started in gullies by planting sprigs (small pieces of sod) or by covering the joints of freshly cut mature stems with 1 to 2 inches of wet soil. Reed canarygrass shoots will push up through as much as 6 to 8 inches of sediment. Seed often has low germination, so pay attention to the PLS seeding rate. Drought resistant and will grow on upland sites. Generally, legumes sown with this grass are not successful, especially in wet sites. Seed is used by game birds.

DEERTONGUE

(*Panicum clandestinum*)

Type of plant: Grass

Origin: Native

Lifespan: Perennial

Season of major growth: Warm

Lower pH limit: 4.0

Planting materials: Seed (stratify for spring seeding)

Seeding rate: 6 to 8 lb/acre in mixture, 12 to 15 lb/acre alone

Time of seeding: Late fall, winter, spring (stratified seed)

Superior cultivars: Tioga

Rate of establishment: Moderate to slow

Major uses: Watershed protection, wildlife habitat

Regions where adapted: All except Southern Lignite

Comments: Selected for use on acid minesoils because it frequently volunteers on low fertility and eroded acid sites. Stands usually develop slowly, but once established they persist without additional fertilizer or maintenance. Probably adapted to all coal mining regions, but has been tested on minesoils mostly in the Northeast. Seed becomes dormant soon after it is harvested and requires cold stratification to produce acceptable germination. Late fall and winter seedings allow natural stratification of seed. Before spring seeding, stratify seed by moist refrigeration at about 37°F for 4 weeks. Deer and turkey use seed and foliage in the rosette stage (new green growth). Stands establish best where seeded alone, but obviously will have to be sown in mixture with species that produce quick ground cover.

'KENTUCKY-31' TALL FESCUE

(*Festuca arundinacea*, Selection Ky-31)

Type of plant: Grass

Origin: Introduced

Lifespan: Perennial

Season of major growth: Cool

Lower pH limit: 4.5

Planting materials: Seed

Seeding rate: 10 to 15 lb/acre in mixtures, 20 to 30 lb/acre alone

Time of seeding: Spring and fall

Rate of establishment: Moderate

Major uses: Watershed protection (medium to long-term cover); forage (pasture and hay)

Regions where adapted: All

Comments: Most used and most versatile of the grasses suited for vegetating surface mines. Adapted to a wide range of environmental conditions, including wet, droughty, acid, and alkaline soils. Stand establishment is reasonably fast, but usually should be sown with a "quick cover" grass such as rye in the fall, or weeping lovegrass in mid to late spring. As with most cool-season grasses, stands usually do not thrive unless mixed with a legume or refertilized occasionally. Makes luxuriant growth under black locust. Usually becomes the minor species in mixtures with sericea lespedeza or crownvetch. Value for wildlife, especially for game birds, considered low by most biologists, but sometimes provides winter forage for deer. Generally not recommended for planting in or near wildlife habitat areas. Most of the tall fescue seed available today is Kentucky-31. 'Alta" tall fescue is similar but seldom used. Kenhy, a new variety of tall fescue, is superior to Ky-31 in forage quality and palatability to livestock, but its adaptability to minesoils is uncertain.

INDIANGRASS
(*Sorghastrum nutans*)

Type of plant: Grass

Origin: Native

Lifespan: Perennial

Season of major growth: Warm

Lower pH limit: 4.5

Planting materials: Seed

Seeding rate: 5 to 12 lb/acre in mixtures

Time of seeding: Spring

Superior cultivars: Cheyenne, Osage

Rate of establishment: Slow to moderate

Major uses: Wildlife habitat, forage, watershed protection (long-term cover)

Regions where adapted: All

Comments: Native to all Eastern States and in some regions will invade naturally in areas where woody vegetation is controlled, such as under powerlines and on roadsides. Can be sown in mixtures with other native grasses and legumes to help develop or restore a facsimile of native grassland types. It is also possible, but more difficult, to establish this grass in pure stands. Like that of the bluestems, Indiangrass seed is light and fluffy, and is more difficult to sow than seed of most other species. Application of fertilizer will help establish new seedings but established stands generally require little or no maintenance fertilization. Clumps of this grass provide some of the cover requirements for some species of game birds and small mammals. Produces good summer forage for livestock. Responds to spring burning with improved vigor, greater forage production, and more rapid stand development. Superior cultivars listed are adapted to most of Interior Coal Region, but check for locally recommended cultivars, especially in western and southwestern areas. Superior cultivars from Appalachian ecotypes are being selected, but seed is not yet available commercially. A selection (TO 2936) by the SCS Plant Materials Center, Quicksand, Kentucky, shows promise for use in Northern Appalachia.

WEEPING LOVEGRASS
(*Eragrostis curvula*)

Type of plant: Grass

Origin: Introduced

Lifespan: Perennial

Season of major growth: Warm

Lower pH limit: 4.0

Elevation limit: Avoid higher elevation in Appalachian Region

Planting materials: Seed

Seeding rate: 1 to 3 lb/acre in mixtures, 4 to 6 lb/acre alone

Time of seeding: Spring to early summer

Superior cultivars: Morpa, Ermelo

Rate of establishment: Rapid

Major uses: Erosion control (quick, temporary cover), forage

Regions where adapted: Southern two-thirds of Appalachian, southern third of Interior, Southern Lignite

Comments: Not winter-hardy in the northern two-thirds of the Interior Coal Provinces or northern third of Appalachian Region. One of the most tolerant to extremely acid minesoils, has grown well on some minesoils with pH 3.8. Establishes cover easily and quickly, but may be relatively short-lived (2 to 4 years) unless foliage is removed by mowing, burning, or grazing. Compatible with many other species and in much of the East is used mainly as quick, temporary cover component in a mixture with perennial grasses and legumes, especially in mid- to late-spring seedings. Although it provides good initial cover, gradually gives way to the other perennial species. Suited for warm dry sites such as south-facing slopes. Young growth of herbage can be used for pasture, but mature plants are relatively unpalatable to livestock. Because of its tiny seed, only a low seeding rate is needed. Where used in mixtures, exceeding the recommended seeding rate may cause extremely dense stands that retard the establishment of the perennial companion species. Dense stands burn readily in dry periods when plants are dormant, so the use of this grass for ground cover in tree plantations is risky. Common and 'Morpa" are the cultivars most tolerant of acid minesoils.

FOXTAIL MILLET
(*Setaria italica*)

Type of plant: Grass

Origin: Introduced

Lifespan: Annual

Season of major growth: Warm

Lower pH limit: 4.5

Elevation limit: Avoid high elevations in Appalachian Region

Planting materials: Seed

Seeding rate: 10 to 15 lb/acre in mixture, 20 to 30 lb/acre alone

Time of seeding: Late spring to midsummer

Superior cultivars: German

Rate of establishment: Rapid

Major uses: Erosion control (quick, temporary cover), wildlife food

Regions where adapted: Appalachian and Interior except as noted below

Comments: This summer annual grows rapidly and matures in 60 to 80 days after seeding. Requires high summer temperatures for best growth. Plants are leafy with slender stems that provide dense cover while green, but the plant residue decays much more rapidly than that of sorghum, Sudangrass, pearl millet, or Japanese millet. Thus, foxtail millet is less suitable as an *in situ* mulch grown in place for winter cover. The German strain has somewhat heavier stems and requires a longer growing period than common foxtail millet. Seed provides food for songbirds. Use for quick, temporary cover in seeding mixes with perennial grasses and legumes. Recommended for all Coal Regions except Southern Lignite Region and southern-most part of Appalachian Region and Western Interior Province.

JAPANESE MILLET
(*Echinochloa crusgalli* var. *frumentacea*)

Type of plant: Grass

Origin: Introduced

Lifespan: Annual

Season of major growth: Warm

Lower pH limit: 4.5

Planting materials: Seed

Seeding rate: 8 to 12 lb/acre in mixture, 20 to 25 lb/acre alone

Time of seeding: Late spring-early summer

Rate of establishment: Rapid

Major uses: Erosion control (quick, temporary cover), wildlife habitat

Regions where adapted: Northern Appalachian, Interior Coal

Comments: Use as quick-cover companion crop with perennial grasses and legumes, or sow alone for growing mulch in place. Similar to foxtail millet but taller, coarser, more productive of herbage, and provides more residue for overwinter cover. Grows well in wet soils and low places with occasionally standing water. Seed eaten by song and game birds. Used for food plantings for game birds in swampy areas and around ponds. Japanese millet is a cultivated variety of wild barnyard grass. Grows better than foxtail millet in cool regions. Not recommended for southernmost areas.

PEARL MILLET
(*Pennisetum americanum*)

Type of plant: Grass

Origin: Introduced

Lifespan: Annual

Season of major growth: Warm

Lower pH limit: 4.0 to 4.5

Planting materials: Seed

Seeding rate: 8 to 12 lb/acre in mixture, 20 to 25 lb/acre alone

Time of seeding: Spring to midsummer

Superior cultivars: Gahi-l, Starr

Rate of establishment: Rapid

Major uses: Erosion control (quick, temporary cover)

Regions where adapted: Southern Appalachian, southern part of Interior, southern Lignite

Comments: Used in southern climates primarily for quick, temporary cover in late-spring to midsummer seedings. Sow as companion crop with perennials or alone for growing mulch in place. Plant or sow perennials into the residue (mulch) the following spring. Plant residue is composed of large stems that persist and provide mulch through the second year and sometimes longer. Pearl millet may grow 6 to 8 feet tall or more in good moisture conditions on fertile minesoil. Will outyield Sudangrass in the Southeast and is free of prussic acid. Seeds are used by songbirds. Herbage may be used for pasture, fodder, or ensilage in agricultural situations. Not recommended in northern two-thirds of Interior Coal Region.

OATS
(*Avena sativa*)

Type of plant: Grass

Origin: Introduced

Lifespan: Annual

Season of major growth: Cool

Lower pH limit: 4.5

Planting materials: Seed

Seeding rate: 30 to 50 lb/acre in mixture, 60-90 lb/acre alone

Time of seeding: Spring, fall

Superior cultivars: Consult local agricultural agencies for recommended cultivar

Rate of establishment: Rapid

Major uses: Erosion control (quick, temporary cover), silage, feed crop

Regions where adapted: All

Comments: Most often used as a companion crop with perennial species in spring seedings in northern climates. Fall-seeded (winter) varieties seldom available or used in the northern climates; more often used in southern climates. Could be harvested for silage or grain followed by sowing of perennial species into the stubble.

ORCHARDGRASS
(*Dactylis glomerata*)

Type of plant: Grass

Origin: Introduced

Lifespan: Perennial

Season of major growth: Cool

Lower pH limit: 4.5

Planting materials: Seed

Seeding rate: 5 to 8 lb/acre in mixtures, 10 to 15 lb/acre alone

Time of seeding: Spring, late summer to early fall

Superior cultivars: Consult local agricultural agencies for recommended cultivars

Rate of establishment: Moderate to rapid

Major uses: Forage; wildlife habitat, watershed protection

Regions where adapted: All except as noted below

Comments: Similar to Ky-31 tall fescue in growth habits and tolerance to minesoils, but generally is less persistent, especially where fertilization and management are not practiced to maintain it. Considered superior to fescue for use in wildlife plantings, especially in food patches and clearings vegetated with herbaceous species for game birds. Where managed properly, considered more desirable than tall fescue as forage for livestock. Grows well in combination with such legumes as red and ladino clovers. More adapted than most grasses to growing in shaded sites. Not recommended for Southern Lignite Region or southwestern part of Interior Coal Region.

REDTOP
(*Agrostis gigantea*)

Type of plant: Grass

Origin: Introduced

Lifespan: Perennial

Season of major growth: Cool

Lower pH limit: 4.0 to 4.5

Planting materials: Seed

Seeding rate: 2 to 4 lb/acre in mixture, 3 to 6 lb/acre alone

Time of seeding: Spring, late summer

Rate of establishment: Moderate to rapid

Major uses: Erosion control (temporary cover)

Regions where adapted: All except as noted below

Comments: Tolerates a variety of soil and moisture conditions. Grows on very acid and clayey soils. Especially adapted to wet sites and poorly drained soils, but is drought resistant when established. Spreads by seed and rhizomes. Forms sod that is useful for controlling erosion on sites with overland flows. Sometimes recommended for fall seedings, though the small plants produce little cover in the fall. Plants initiate new growth and produce rapid cover early the following spring. Redtop is relatively short-lived, especially in mixture with other species; the stands usually give way to the companion species after 3 to 4 years. Value as a forage crop is relatively low. Sometimes used in seed mixtures primarily to indicate areas or spots of minesoil that are acid or poorly drained. Not recommended for Southern Lignite Region or southwestern part of Interior Coal Region.

RYE
(*Secale cereale*)

Type of plant: Grass

Origin: Introduced

Lifespan: Annual

Season of major growth: Cool

Lower pH limit: 4.5

Planting materials: Seed

Seeding rate: 30 to 60 lb/acre in mixture, 80 to 120 lb/acre alone

Time of seeding: Fall

Superior cultivars: Balbo, Abruzzi

Rate of establishment: Rapid

Major uses: Erosion control (quick, temporary cover)

Regions where adapted: All

Comments: Used widely as a quick-cover companion crop with perennial species. It is most useful and effective in fall seedings and can be sown alone to produce mulch in place. The plants could be killed with herbicide the following spring and perennial grasses and legumes sown into the dead material. Another seeding option is to not use herbicide but sow the perennial species into the matured rye in late summer. Harvesting the rye grain and seeding perennial herbs into the stubble after harvest is another option. Seed germinates rapidly; seedlings are vigorous and quickly provide ground cover. Rye can be sown later into the fall than most species and still be expected to produce some winter cover. Superior cultivars normally are recommended, but common rye, also called winter rye, is suitable for cover crop. Seeding in spring usually produces sparse stands and cover.

ANNUAL RYEGRASS
(*Lolium multiflorum*)

Type of plant: Grass

Origin: Introduced

Lifespan: Annual

Season of major growth: Cool

Lower pH limit: 4.5

Planting materials: Seed

Seeding rate: 4 to 7 lb/acre in mixtures, 20 to 25 lb/acre alone

Time of seeding: Fall or spring (south); spring (north)

Rate of establishment: Rapid

Major uses: Erosion control (quick, temporary cover), forage

Regions where adapted: All

Comments: This winter annual also known as Italian ryegrass. Commercial seed of this species may include seed of common or domestic ryegrass, which is a genetic mixture of Italian and perennial ryegrasses. Annual ryegrass grows 2 to 3 feet tall and is taller and more vigorous than common and perennial ryegrasses. Can be sown in the fall or early spring, but spring seeding is advised where winters are severe. Used mostly for quick, temporary cover and sown in mixtures with long-lived (perennial) grasses and legumes. The rapid-growing vigorous plants of annual ryegrass can compete strongly with the companion perennials; thus, its seeding rate should not exceed the recommended rate. In warmer climates, ryegrass can be sown alone in the fall for winter cover, and the complement of perennial species in the seed mixture sown the following spring or fall. Can be pastured or cut for hay in agricultural situations, but such use on newly vegetated minesoils is not advised. Value for use by wildlife is limited.

PERENNIAL RYEGRASS
(*Lolium perenne*)

Type of plant: Grass

Origin: Introduced

Lifespan: Perennial

Season of major growth: Cool

Lower pH Limit: 4.5

Planting materials: Seed

Seeding rate: 5 to 10 lb/acre in mixtures, 20 to 25 lb/acre alone

Time of seeding: Fall or spring (south), spring (north)

Rate of establishment: Rapid

Major uses: Erosion control (quick, temporary cover), forage

Regions where adapted: All except northern most latitudes

Comments: A short-lived perennial. Plants usually live only 2 to 3 years and do not reseed successfully to perpetuate the stand. Plants grow 1 to 2 feet tall. Used mostly to provide quick temporary cover where sown in mixture with long-lived perennial grasses and legumes. Less vigorous and less competitive than annual ryegrass with companion species. In warmer climates can be sown alone in the fall for winter cover. Seeding or planting of permanent or long-lived perennial species could be made the following year. Spring seeding is advised in the northern latitudes because winter killing may occur. Can be used for pasture or hay, especially in the South, but newly seeded minesoils should not be grazed until perennial vegetation is well established.

SORGHUM
(*Sorghum bicolor*)
SUDANGRASS
(*Sorghum sudanense*)

Type of plant: Grass

Origin: Introduced

Lifespan: Annual

Season of major growth: Warm

Lower pH limit: 4.5 to 5.0

Planting materials: Seed

Seeding rate: 15 to 20 lb/acre in mixtures, 25 to 40 lb/acre alone

Time of seeding: Spring to midsummer

Superior cultivars: Piper Sudangrass. Consult local agricultural agencies for recommendations on sorghum and sorghum-Sudangrass hybrids

Rate of establishment: Rapid

Major uses: Erosion control (quick, temporary cover), wildlife food

Regions where adapted: All

Comments: The sorghums, Sudangrass, and sorghum-Sudangrass hybrids are drought resistant and are useful as quick, temporary cover component of herbaceous mixtures sown in late spring to midsummer. They also can be sown alone to grow mulch in place; perennial species can be planted or sown into the plant residue (mulch) the following spring. Residues from these species usually last through the second year. In the southernmost areas, seeding can be done throughout the summer. There are several types and many cultivars of sorghums. They are classified on the basis of use as (1) grass sorghum; (2) grain sorghum; (3) forage sorghum; (4) syrup sorghum; and (5) broomcorn. The grass sorghums include Sudangrass and the sorghum-Sudangrass hybrids and are the most likely choice to seed for quick cover for erosion control. Grain sorghums can be used in wildlife food patches and for livestock feed in agricultural situations. Forage and grass sorghums can be used for pasture, silage, or fodder in agricultural land uses. Superior cultivars and hybrids have not been delineated specifically for minesoil plantings. CAUTION: When grown under certain environmental conditions, the herbage of these species can be poisonous to livestock.

SWITCHGRASS
(*Panicum virgatum*)

Type of plant: Grass

Origin: Native

Lifespan: Perennial

Season of major growth: Warm

Lower pH limit: 4.0 to 4.5

Planting materials: Seed

Seeding rate: 2 to 5 lb/acre in mixture, 5 to 12 lb/acre alone

Time of seeding: Spring

Superior cultivars: Blackwell, Cave-in-Rock, Kanlow, Caddo

Rate of establishment: Moderate to slow

Major uses: Watershed protection (long-term cover), forage, wildlife habitat

Regions where adapted: All

Comments: Has been used on minesoils in most of the eastern and midwestern coal States and could be used in all of them. Plants are tall, large-stemmed, and spread by short rhizomes and seed. Unlike some native grasses, switchgrass seed is easy to handle and sow. Stands usually require 2 to 4 years to develop good cover. Once established, stands require little or no maintenance except occasional burning where left solely for cover. They can be highly productive of summer forage if managed properly. A mixture of switchgrass and other native grasses such as Indiangrass, big bluestem, and little bluestem provides a diversity of species similar to that in some natural grassland areas. It also provides cover for some game birds and mammals. A light companion seeding of rye, wheat, or oats helps provide site protection while the switchgrass becomes established. 'Blackwell" is the cultivar used most often on eastern minesoils. It grows about 4 feet tall. Other cultivars are available for selected uses and some are recommended for specific areas. There are many natural ecotypes of switchgrass, so selections can be made for different environmental conditions.

TIMOTHY
(*Phleum pratense*)

Type of plant: Grass

Origin: Introduced

Lifespan: Perennial

Season of major growth: Cool

Lower pH limit: 4.5 to 5.0

Planting materials: Seed

Seeding rate: 4 to 7 lb/acre in mixtures

Time of seeding: Late summer-early fall, spring

Superior cultivars: Consult local agricultural agencies for recommendations

Rate of establishment: Moderate

Major uses: Forage, wildlife habitat, erosion control

Regions where adapted: Northern Appalachian, Interior except southern most part

Comments: Adapted to cool, humid climates. Used mostly in northern half of eastern United States. Used primarily for hay. Often used on mined lands as a substitute for Ky-31 tall fescue in plantings for wildlife habitat. Should be sown with legumes and other grasses. Can be sown in the fall with rye or winter wheat, and companion legumes such as red clover or alfalfa sown the following spring. A relatively short-lived perennial, usually persists for about 5 years, especially where not managed for forage production. Can tolerate partial shading.

WINTER WHEAT

(*Triticum aestivum*)

Type of plant: Grass

Origin: Introduced

Lifespan: Annual

Season of major growth: Cool

Lower pH limit: 4.5

Planting materials: Seed

Seeding rate: 30 to 60 lb/acre in mixture, 80 to 120 lb/acre alone

Time of seeding: Fall

Superior cultivars: Consult local agricultural agencies for recommendations

Rate of establishment: Rapid

Major uses: Erosion control (quick, temporary cover), grain crop, wildlife habitat

Regions where adapted: All

Comments: Similar to rye in growth habit and adaptation to site and minesoil conditions. Can be used as a quick-cover companion crop with perennial species or can be sown alone to produce mulch in place. In some areas, used for quick cover and harvested for the grain crop. The stubble and straw residue after harvest provide soil cover until fall when perennial herbs can be sown or another crop of wheat planted and the grain-harvest cycle repeated. The straw residue adds organic matter to the minesoil, improving the minesoil for subsequent growth of perennial plants. Wheat grain is preferred over rye as food by most wildlife species. Recommendations on fall seeding dates and on best varieties should be obtained from local agricultural agents.

Table 17. Grass species of lesser importance or use.

Common and Scientific Name	*Origin**	*Lifespan†*	*Growth* Season	*Lower pH* Limit	*Seeding Rate‡ (lb/acre)* PLS	*Seeding* Period
Bahiagrass *(Paspalum notatum)*	I	P	Warm	4.5	25-35; 35-45	Fall; spring
Comments: Adapted climatically to the Gulf Coast Area, so use in reclamation limited to Southern Lignite Region. Forms dense, tough sod even on sandy soils. Ideal species for erosion control and grassed waterways. Also used for pasture. Can be seeded most anytime of year but fall through spring best. Pensacola most common and most used variety.						
Highland bentgrass *(Agrostis tenuis)*	I	P	Cool	4.0-4.5	2-4; 3-6	Fall; spring
Comments: A variety of Colonial bentgrass naturalized in Northeastern States. Similar to and sometimes substituted for redtop in seeding mixtures. Value for reclamation is poorly documented because of limited use. Northern Appalachian Region.						
Canada bluegrass *(Poa compressa)*	I	P	Cool	4.5	5-10; 15-25	Spring; fall
Comments: Low-growing species similar to Kentucky bluegrass but better adapted to acid, infertile, and droughty soils. "Reubens" is a superior cultivar. Has potential as little-competing cover species in forestry land use. Northern Appalachian and northern part of Interior Regions.						
Kentucky bluegrass *(Poa pratensis)*	I	P	Cool	5.5	5-10; 15-25	Spring; fall
Comments: Low-growing, shallow-rooted sod-former. Not drought tolerant. Slow to establish cover and best adapted to well-drained topsoiled sites in northern latitudes. Can be used in Northern Appalachian and most of Interior Region. May have limited value for revegetating minesoils.						
Caucasian bluestem *(Bothriochloa caucasica)*	I	P	Warm	5.0	1-3; 3-6	Spring
Comments: Used for range, pasture, and hay in southern part of Western Interior Province and northern parts of Lignite Region. Performed well on mine spoils in western and eastern Kentucky. Has potential for use in much of East. Good seedling vigor. Can be sown with legumes such as Appalow or Serala sericea lespedeza, or birdsfoot trefoil for cover, pasture, or hay. Plains and WW-spar bluestems are similar and potentially useful on minesoils, at least in Oklahoma and Kansas.						
King Ranch bluestem *(Bothriochloa ischaemum)*	I	P	Warm	5.0	2-6	Spring
Comments: Use for range and pasture in lignite region and southernmost part of Western Interior Province (Oklahoma).						
Buffalograss *(Buchloe dactyloides)*	N	P	Warm	4.5	5-10; 10-20	Spring
Comments: Adapted to droughty minesoils. Low growing. Spreads by stolons. Mix with other native grasses for rangeland seedings. Slow to moderate establishment. Excellent forage. Used mostly in Kansas and Oklahoma.						
Corn *(Zea mays)*	N	A	Warm	5.5	See below	Mid-spring
Comments: Adapted varieties available for most parts of Eastern Coal Regions, but in mineland reclamation corn is an important crop mainly on replaced prime farmland soils in the cornbelt area of the Interior Region. Prior to PL 95-87, corn was successfully grown on "wheel spoils" in that area. Several years of alfalfa usually preceded planting of corn. Follow local agronomic guidelines for selecting varieties, seeding rates, and fertilizer needs.						
Dallisgrass *(Paspalum dilatatum)*	I	P	Warm	4.5	7-12	Spring
Comments: Bunchgrass that seldom makes full cover. Sow with legumes or other grasses. Good pasture. Seed used by song and game birds. Adapted to southern areas.						
Red fescue *(Festuca rubra)*	I	P	Cool	4.5	4-6; 8-10	Spring; fall
Comments: Long-lived in northern latitudes and high elevations. Adapted to most of Interior region. Fairly shade tolerant and low growth habit; suitable for ground cover with forest plantings. Capable of making dense cover, but somewhat slow in establishment. Several varieties available.						
Sideoats grama *(Bouteloua curtipendula)*	N	P	Warm	4.5	2-4	Spring
Comments: Sow in mixtures with other native grasses for rangeland. Establishes fairly quickly. Good forage. Native to most Eastern States. 'Elreno" is a superior cultivar. Used mostly in Kansas, Oklahoma, Missouri, and Texas.						
Browntop millet *(Brachiaria ramosa)*	I	A	Warm	4.5	15-20; 20-30	Late spring
Comments: Adapted to southern latitudes. For quick, temporary cover in summer seedings. Food for song and game birds. Used mostly in Oklahoma and throughout Southern Lignite Region.						
Tall oatgrass *(Arrhenatherum elatius)*	I	P	Cool	4.5	10-12; 15-20	Spring
Comments: Drought resistant. Moisture and temperature requirements similar to orchardgrass. Plants persist but not in dense stands. Limited seed supply due partly to harvesting difficulties. For Northern Appalachian and Interior Region except southwestern part. Tualatin is a superior cultivar used in mineland plantings in the East.						
Western wheatgrass *(Agropyron smithii)*	N	P	Cool	4.5	4-6; 10-20	Spring
Comments: Rhizomatous, sod-former spreads onto adjacent acid soils. Useful in clayey soils, moist swales, and grassed waterways. Used mostly in Kansas and Oklahoma. 'Barton' recommended cultivar.						

*I = Introduced; N = Native.
†A = Annual; P = Perennial.
‡First rate is recommended rate for use in mixtures; second rate for seeding alone. Use only in mixtures where one rate (range of rates) is shown.

ALFALFA
(*Medicago sativa*)

Type of plant: Forb-legume

Origin: Introduced

Lifespan: Perennial

Season of major growth: Cool

Lower pH limit: 5.5

Planting materials: Seed

Seeding rate: 4 to 12 lb/acre in mixtures, 10 to 18 lb/acre alone

Time of seeding: Spring, late summer

Superior cultivars: Consult local agricultural agencies for recommendations

Rate of establishment: Rapid to moderate

Major uses: Forage, erosion control, wildlife habitat

Regions where adapted: Northern Appalachian, Interior

Comments: This widely grown species is one of the most valuable forage plants in the United States. It thrives on fertile, nonacid, and well-drained soils. Use on mined lands has been mostly in areas where minesoils do not require additions of lime or fertilizer. Not recommended for acid minesoils unless the soils are limed to near neutrality (pH 7.0) and fertilized adequately with phosphorus. Use primarily on areas that will be managed for forage production or wildlife openings. Makes good pasture when mixed with orchardgrass, smooth bromegrass, or tall fescue. Although generally considered a cool-season species, with adequate precipitation or irrigation can make succulent growth in the summer as well as in spring and fall. Stands are subject to damage by alfalfa weevil and several diseases. Some varieties are not winter-hardy. Consult local agricultural authorities for advice on cultivars that are winter hardy and resistant to diseases and insects. In northern latitudes, stands usually are established more successfully by seeding in spring than in fall. Seldom grown in the deep South.

LADINO CLOVER
(*Trifolium repens*)
WHITE CLOVER
(*Trifolium repens*)

Type of plant: Forb-legume

Origin: Introduced

Lifespan: Perennial

Season of major growth: Cool

Lower pH limit: 5.5

Planting materials: Seed

Seeding rate: 2 to 4 lb/acre in mixtures

Time of seeding: Spring, late summer to fall

Superior cultivars: Ladino, Regal, Tillman

Rate of establishment: Moderate to rapid

Major uses: Wildlife habitat, forage

Regions where adapted: All

Comments: Common white clover is used for pasture throughout the eastern United States. However, on minesoils it is best used primarily to provide diversity in species composition, especially in food patches or openings planted for wildlife. Should be planted with grasses and other legumes. Planted alone, white clover provides inadequate ground cover during the winter. Due to peculiar growth and reproductive habits, there is no assurance of stand persistency from year to year. Although usually considered a perennial, much of the new growth each year may volunteer from seed. Ladino, a large form of white clover, is the most widely sown cultivar for use as hay and pasture.

RED CLOVER
(*Trifolium pratense*)

Type of plant: Forb-legume

Origin: Introduced

Lifespan: Biennial-perennial

Season of major growth: Cool

Lower pH limit: 5.0

Planting materials: Seed

Seeding rate: 4 to 8 lb/acre in mixtures, 8 to 12 lb/acre alone

Time of seeding: Spring, later summer

Superior cultivars: Kenland, Pennscott, Redland

Rate of establishment: Rapid

Major uses: Erosion control (short-term cover), wildlife habitat, forage

Regions where adapted: All except Southern Lignite and southern most part of Appalachain

Comments: One of most important hay crops grown on farms in the Northeastern States, and sometimes used for hay and pasture in Interior Coal Region. Its use on mined lands is primarily to improve or enrich the minesoil and to add to species diversity in food plantings for wildlife. Should be sown with long-lived grasses and legumes because it has a biennial or short-lived perennial growth habit. Although stands of red clover thin out, a few plants will continue to volunteer for several years from seed. Requires a high level of soil phosphorus. Less drought resistant than alfalfa and best adapted where adequate moisture is available throughout the growing season. Subject to damage and stand reduction by several diseases and insect pests. Seedings usually more successful in spring than in fall.

CROWNVETCH
(*Coronilla varia*)

Type of plant: Forb-legume

Origin: Introduced

Lifespan: Perennial

Season of major growth: Cool

Lower pH limit: 5.0 (see comments)

Planting materials: Seed; crowns

Seeding rate: 5 to 10 lb/acre in mixtures, 15 to 20 lb/acre alone

Time of seeding: Spring, late summer to early fall (plant crowns in spring to early summer)

Superior cultivars: Emerald, Penngift, Chemung

Rate of establishment: Slow

Major uses: Watershed protection (long-term cover), forage, esthetics

Regions where adapted: All

Comments: One of the best species for providing continuous, maintenance-free cover for erosion control. Plants are spread by seed and by rhizomes; thus, are especially useful for developing total cover on steep slopes. Usually established by direct seeding, though stands can be started by transplanting crowns (small plants) from older established stands. Seeded stands established most easily on minesoils with pH 5.5 and higher, but plants will spread and grow on minesoils with pH 4.5 and sometimes lower. Sow in mixture with a quick-cover companion grass such as weeping lovegrass or perennial ryegrass. A few plants of crownvetch established the first year are capable of developing full cover after 3 to 4 years and suppressing associated vegetation. May compete strongly with tree seedlings. Can be used for forage but stands may be weakened by overgrazing or by taking more than one cutting of hay annually. Seeds mature over a period of several weeks, making efficient and effective seed harvest difficult. Commercial seed is sometimes in short supply. Emerald most used cultivar in Interior Region; Penngift and Chemung in Appalachian Region.

FLATPEA
(*Lathyrus sylvestris*)

Type of plant: Forb-legume

Origin: Introduced

Lifespan: Perennial

Season of major growth: Warm

Lower pH limit: 4.0

Planting materials: Seed (needs special inoculum)

Seeding rate: 20 lb/acre in mixtures, 30 lb/acre alone

Time of seeding: Spring

Superior cultivars: Lathco

Rate of establishment: Slow

Major uses: Watershed protection (long-term cover)

Regions where adapted: Northern Appalachian and probably most of Interior

Comments: A long-lived viny species with tendril-bearing stems and a climbing growth habit. Stand density increases mostly by rhizomes. Stand development usually is slow but eventually a complete ground cover is established that suppresses associated vegetation and prevents establishment of volunteer plants. Should not be used in combination plantings with trees. Drought resistant and more tolerant than crownvetch and most other legumes of acid minesoils. Primary value is for erosion control on critical slope areas. Where given free choice to graze a number of grasses and legumes, cattle did not eat flatpea but horses did. This species may have greater use in revegetating abandoned than current mined lands. Experience with use in Interior Region is limited, but probably adapted to most of it.

COMMON LESPEDEZA
(*Lespedeza striata*)
KOBE LESPEDEZA
(*Lespedeza striata* var. Kobe)

Type of plant: Forb-legume

Origin: Introduced

Lifespan: Annual

Season of major growth: Warm

Lower pH limit: 4.5

Elevation limit: 2,000 ft at northern limits of range

Planting materials: Seed

Seeding rate: 8 to 15 lb/acre in mixtures, 25 to 30 lb/acre alone

Time of seeding: Spring

Superior cultivars: Kobe

Rate of establishment: Rapid to moderate

Major uses: Wildlife food, forage (hay and pasture), forestry (companion legume with trees)

Regions where adapted: Southern and Central Appalachian, Southern Lignite, southern part of Interior

Comments: Common lespedeza also called Japanese lespedeza, Japanese clover, and striate lespedeza. Has low-growth form and less productive of herbage than improved variety Kobe, which is the most widely used and most familiar cultivar of this lespedeza. Similar to Korean lespedeza in growth form but it matures later and is not adapted as far north. More tolerant than Korean of high levels of manganese in the soil. Reseeds readily in its adapted climatic range. Generally used for quickly establishing a legume in mixtures with grasses or with grasses and perennial legumes. Recommended as ground-cover species for use with pine in Southern Pine Region. Growth stops after first killing frost and cover value of plant residue diminishes as winter progresses.

KOREAN LESPEDEZA
(*Lespedeza stipulacea*)

Type of plant: Forb-legume

Origin: Introduced

Lifespan: Annual

Season of major growth: Warm

Lower pH limit: 5.0

Elevation limit: 2,000 ft in Northern Appalachians

Planting materials: Seed

Seed rate: 6 to 12 lb/acre in mixtures, 20 to 25 lb/acre alone

Time of seeding: Spring

Rate of establishment: Moderate to rapid

Major uses: Wildlife food, forage (hay and pasture), forestry (companion legume with trees), watershed (early cover)

Regions where adapted: All except as noted below

Comments: Reseeds readily in adapted climatic range; thus, it can be considered as a long-term component of vegetative cover. Provides early or quick legume component in spring-sown grass-legume mixtures. Plant residue provides poor ground cover in winter. More sensitive than sericea and Kobe lespedeza to excess soil manganese and soil acidity. Seed is preferred food by quail. Produces high-quality hay. Similar to Kobe lespedeza but has shorter growing season and can be used farther north. Generally not recommended for northern most parts of Appalachian and of Interior Regions. An early maturing variety, Iowa 6, has been used in northern part of Interior Region.

SERICEA LESPEDEZA
(*Lespedeza cuneata*)

Type of plant: Forb-legume

Origin: Introduced

Lifespan: Perennial

Season of major growth: Warm

Lower pH limit: 4.5

Elevation limit: 2,000 ft in Northern Appalachian

Planting materials: Seed

Seeding rate: Hulled and scarified seed—10 to 20 lb/acre in mixtures, increase rate by 10 to 15 lb/acre for unscarified or unhulled seed

Time of seeding: Late winter to early summer (If sown in midsummer to early fall, at least one-half of seed should be unhulled)

Superior cultivars: Interstate, Appalow (a low-growing form), Caricea, Serala

Rate of establishment: Slow

Major uses: Watershed protection (long-term cover), esthetics, forage

Regions where adapted: Central and Southern Appalachian, Lignite, southern third of Interior

Comments: Used widely for erosion control and soil building throughout the Central and Southern Appalachians and the South. Use in northern latitudes is limited by short growing season that prevents seed maturity. Stand establishment is relatively slow; thus, should be sown with a quick-cover grass such as weeping lovegrass. In mixture with grass, usually becomes the dominant species after 3 to 4 years. Usually forms dense stands that retard the natural invasion of other plants. Considered low in value for wildlife by most biologists. Can be used for grazing and cut for hay when forage is young and tender (plants should not be more than 10 to 12 inches tall for these uses). Benefits tree growth in combination plantings provided trees are able to grow above the lespedeza. Stands are weakened or eliminated when shaded by forest species. Provides long-term or permanent cover that requires little or no maintenance.

WHITE SWEETCLOVER
(*Melilotus alba*)
YELLOW SWEETCLOVER
(*Melilotus officinalis*)

Type of plant: Forb-legume

Origin: Introduced

Lifespan: Biennial

Season of major growth: Cool

Lower pH limit: 5.5

Planting materials: Seed (scarified)

Seeding rate: 4 to 7 lb/acre in mixture, 10 to 15 lb/acre alone

Time of seeding: Spring

Rate of establishment: Rapid

Major uses: Erosion control (quick cover)

Regions where adapted: All except as noted below

Comments: Generally considered intolerant of strongly acid soils, but resistant to drought. Often used in mixtures because it makes rapid growth and quickly provides a vegetative cover. On suitable soils may suppress slower growing companion perennial species, especially where its seeding rate is excessive. Plants mature the second year, produce seed, and die. New plants may volunteer from seed most years thereafter. A valuable plant for bee pasture (honey production). In agriculture, used primarily as a soil-improving crop. Can be used for hay and pasture, but livestock bloat is a potential hazard when grazed. Annual varieties of white sweetclover are available. Planting the yellow blossom type is recommended. Adapted and used in all regions except eastern part of Lignite Region.

BIRDSFOOT TREFOIL
(*Lotus corniculatus*)

Type of plant: Forb-legume

Origin: Introduced

Lifespan: Perennial

Season of major growth: Cool

Lower pH limit: 4.5

Planting materials: Seed

Seeding rate: 5 to 8 lb/acre in mixtures, 10 to 12 lb/acre alone

Time of seeding: Spring, late summer to early fall

Superior cultivars: Empire, Viking, Mansfield, Dawn, Fergus

Rate of establishment: Rapid to moderate

Major uses: Watershed protection (medium-term cover), forage

Regions where adapted: Northern Appalachian; Interior

Comments: This relatively low-growing legume, though adapted to most of the Interior Coal Region, grows best in the northern climates. Stands may be easily established near the southern limits of the adapted regions but life span of the plants usually is shorter than in northern climates. Has high tolerance to salt and higher tolerance than most legumes to excess manganese in minesoils. Plants are smaller, less aggressive, and inferior in cover qualities compared with those of crownvetch and sericea lespedeza. Most useful for erosion control and for forage where sown in mixture with a grass such as tall fescue, timothy, or orchardgrass. The cultivar Empire has a more decumbent growth and is more winter-hardy than Viking or Mansfield. Viking has better seedling vigor. Dawn is a disease-resistant cultivar selected in southern Missouri. Fergus is a recent release from Kentucky. Narrowleaf trefoil (var. *tenuifolium*) is a linear-leaved variant that has a more prostrate growth form than birdsfoot. Its performance is similar to that of birdsfoot on minesoils.

FORBS—NONLEGUMES

JAPANESE FLEECEFLOWER
(*Polygonum cuspidatum*)

Type of plant: Forb-nonlegume

Origin: Introduced

Lifespan: Perennial

Season of major growth: Warm

Lower pH limit: 3.5

Planting materials: Seed, crowns

Seeding rate: 3 to 5 lb/acre

Time of seeding: Spring

Superior cultivars: *v. compactum* (dwarf fleeceflower)

Rate of establishment: Slow

Major uses: Watershed protection, cover and food for wildlife, esthetics

Regions where adapted: Northern and Southern Appalachian, Interior

Comments: This escaped ornamental, also called Japanese Knotweed and Mexican bamboo, is a large, multistemmed, and heavily branched forb that grows up to 8 feet tall. It is sometimes called a shrub because the heavy robust stems give the plants a shrublike appearance. However, the stems die back to the ground each fall and new growth arises in the spring from root crowns and rhizomes. The plants produce an abundance of seed, and when in full bloom have a fleecy appearance. Will grow and spread on extremely acid minesoil. Some plants have been found growing on minesoil with a pH as low as 3.2. A good erosion control plant, especially for extremely acid spoils, because it spreads by seed into gullies and over considerable distances on barren areas. However, does not spread readily by seed into stands of established vegetation. May be more valuable for revegetating orphan mine lands than current mined ones. Dwarf fleeceflower is a low-growing variety (18 to 30 inches tall) used commercially as an ornamental ground cover. It is less acid tolerant than common fleeceflower. Probably adapted to most of eastern United States, but plantings not documented for minesoils in most of Interior and Lignite Regions.

Table 18. Forb species of lesser importance or use.

Common and Scientific Name	Origin*	Lifespan†	Growth Season	Lower pH Limit	Seeding Rate (lb/acre) PLS‡	Seeding Period
		LEGUMES				
Illinois bundleflower *(Desmanthus illinoensis)*	N	P	Warm	5.0	1-5	Spring
Comments: Drought resistant. Use in range, pasture, and wildlife-habitat seeding mixtures. Component of native tall grass prairie. Used mostly in Kansas, Oklahoma, and Texas.						
Alsike clover *(Trifolium hybridum)*	I	B-P	Cool	5.0	3-5	Spring; fall
Comments: Short-lived (dies after 2 years). Adapted to wet soils and sites with overland flows and to soils too acid for red clover. Seed only in mixture with grass. For wet sites, mix with grass such as redtop and Ky-31 fescue. Provides food for wildlife. Better stands usually produced by spring seeding than by fall seeding. Adapted to northern part of Interior Region and Northern Appalachian Region.						
Arrowleaf clover *(Trifolium vesiculosum)*	I	A	Cool	5.0	10-15; 15-25	Fall
Comments: Winter annual for southern climates. Similar to crimson clover in use and adaptability. Reseeds. Amclo, Yuchi, and Meechi are recommended cultivars. Used in Southern Appalachian Region, Oklahoma, and throughout Lignite Region.						
Crimson clover *(Trifolium incarnatum)*	I	A	Cool	5.0	15-25; 25-35	Late summer; fall
Comments: Winter annual used in southern climates. Usually mix with perennials. Can be used alone for winter cover, then sow perennial species the next spring, especially for agricultural uses. Good forage species and has value for wildlife. Reseeding varieties preferred.						
Kura clover *(Trifolium ambiguum)*	I	P	Cool	5.0	6-8; 8-12	Spring; fall
Comments: Slow to establish. Spreads by rhizomes, forms a sod. Drought resistant, also tolerates wet soils. Requires special inoculum. Evaluation of this species in early stage, so seed supply scarce and uncertain. Probably adapted to all regions.						
Subterranean clover *(Trifolium subterraneum)*	I	A	Cool	5.0	15-25; 25-35	Fall
Comments: Reseeding winter annual for eastern part of Lignite Region. Use similar to crimson clover.						
Cowpea *(Vigna unguiculata)*	I	A	Warm	4.5	20-30	Late spring
Comments: Use mainly for summer cover and wildlife food. Provides little residue for winter cover. Mix with sorghum or Sudangrass for overwinter *in situ* mulch. Soil-building and forage crop in agricultural land uses. For Southern Appalachian and Lignite Regions and southern half of Interior Region.						
Prostrate lespedeza *(Lespedeza daurica* var. *schimadai)*	I	P	Warm	4.5	15-20	Spring
Comments: Similar to sericea, but low growing. Potential ground cover species to plant with trees. Not used widely. Probably adapted to most of Interior Region.						
Cicer milkvetch *(Astragalus cicer)*	I	P	Cool	5.0	2-5; 15-20	Spring
Comments: Long-lived legume for dryland conditions. Spreads slowly by rhizomes. Used in Kansas in pasture and range seedings.						
Partridge Pea *(Cassia fasciculata)*	N	A	Warm	5.0	20-30	Spring
Comments: Reseeds, usually in sparse stands. Mainly for wildlife enhancement and esthetics. Choice food for some game bird species. Use in mixtures with grass. Native to all Eastern States, use in all regions.						
Purple prairie clover *(Petalostemum purpureum)*	N	P	Warm		1-3	Spring
Comments: Component of tall grass prairie. For use mainly in seed mixtures of prairie grasses for rangeland and esthetic purposes, from Iowa to Texas. Superior cultivar 'Kaneb.'						
Soybean *(Glycine max)*	I	A	Warm	5.0	30-50	Late spring
Comments: For quick cover in early summer and for wildlife food. Provides little residue for winter cover. Sow with quick cover grasses such as sorghums for overwinter *in situ* mulch. Cash crop on reconstructed prime farmland. Adapted to Interior, Lignite, and Southern Appalachian Regions.						
Bigflower vetch *(Vicia grandiflora)*	I	A	Cool	5.5	15-20	Fall
Comments: Winter annual, similar in appearance to hairy vetch. Can be established by seeding into existing stands of grass. Reseeds itself. Improves nitrogen status of soil. Used for forage and wildlife food and cover. 'Woodford" superior cultivar. Appalachian Regions.						
Hairy vetch *(Vicia villosa)*	I	A	Cool	4.5	20-30; 40-50	Fall
Comments: Winter annual used mainly for erosion control and soil building. Mix with perennial grass such as KY-31 fescue, or sow with rye for overwinter cover, then seed perennials the next year. May have some value for wildlife. Used in all regions.						

Table 18. Forb species of lesser importance or use.

Common and Scientific Name	Origin*	Lifespan†	Growth Season	Lower pH Limit	Seeding Rate (lb/acre) PLS‡	Seeding Period
			NONLEGUMES			
Buckwheat *(Fagopyrum esculentum)*	I	A	Warm	4.5	25-40	Late spring
Comments: Used mainly in Northern Appalachian Region. Mix with other summer annual species to provide diversity in fall and winter foods for song and game birds. Can make late summer cover but plant residue makes poor *in situ* mulch over winter. Excellent bee pasture and visually appealing when in full bloom.						
Common sunflower *(Helianthus annuus)*	N	A	Warm	5.0	6-8	Late spring
Comments: Mix with other summer annual species to provide diversity in fall and winter food for song and game birds. Should not be used alone for cover. Potential use in all regions.						
Maximilian sunflower *(Helianthus maximiliani)*	N	P	Warm	5.0	2-4	Spring
Comments: For use in seed mixtures for rangeland seedings and esthetic purposes in prairie areas from Iowa to Texas. Established successfully with native grasses on reclaimed abandoned spoils in Kansas. Superior cultivars are 'Prairie Gold' and 'Aztec.'						
'Eureka' thickspike gayfeather *(Liatris pycnostachya)*	N	P	Warm		1-3	Spring
'Sunglow' Grayhead prairie coneflower *(Ratibida columnifera* var.)	N	P	Warm		1-3	Spring
'Nekan' Pitcher sage *(Salvia azurea* var *grandiflora)*	N	P	Warm		1-3	Spring
Comments: These three forbs are components of native tall grass prairie. Used mainly in seed mixtures with prairie grasses for rangeland and esthetic purposes in prairie areas from Iowa to Texas. Species utilized by livestock and wildlife.						

* I = Introduced; N = Native.
† A = Annual; P = Perennial; B = Biennial.
‡ First rate is recommended rate for mixtures; second rate for seeding alone. Use only in mixtures where one rate (range of rates) is shown.

GRAY DOGWOOD
(*Cornus racemosa*)
SILKY DOGWOOD
(*Cornus Amomum*)
RED-OSIER DOGWOOD
(*Cornus stolonifera*)

Type of plant: Shrub
Shade tolerance: Silky—Tolerant
Gray—Intermediate
Red-osier—Intermediate

Origin: Native

Lower pH limit: Silky—4.0
Gray—5.0
Red-osier—4.5

Planting materials: Seedlings (1-0)

Major uses: Wildlife food and cover

Regions where adapted: Appalachian, Interior, see note below

Comments: All dogwoods are excellent species for wildlife. The fruit is used by many species of birds and mammals, and the plants provide browse for deer. Silky dogwood has been tested and used more than the others. Tolerates acid conditions better than gray or red-osier dogwoods. Red-osier best suited for moist sites, such as seepage areas and along ponds. Its dense root system provides protection against overland flow. All three species produce fruit in 3 to 5 years. Silky dogwood established successfully by direct seeding. Not tested throughout Interior and Lignite Regions, so extent of use not known.

AMUR HONEYSUCKLE
(*Lonicera maackii*)
MORROW HONEYSUCKLE
(*Lonicera morrowii*)
TATARIAN HONEYSUCKLE
(*Lonicera tatarica*)

Type of plant: Shrub
Intermediate tolerance to shade

Origin: Introduced

Lower pH limit: 5.0

Planting materials: Seedlings (1-0, 2-0)

Superior cultivars: 'Rem Red' and 'Cling red' amur honeysuckle

Major uses: Wildlife food and cover, esthetics and screening

Regions where adapted: All, see note below

Comments: These shrubs, planted in combinations with other woody species, add to the diversity in food and cover for wildlife. Plant growth is slow for the first 2 years and seedlings may be adversely affected by tall herbaceous competition. There is little difference in performance among species, except in date of fruit maturity and geographic adaptability. 'Rem Red' amur and tatarian are adapted over most of the eastern regions. Morrow honeysuckle has been more successful in southern Appalachia. Fruit of Morrow and tatarian matures in June to August and falls from the plant soon after maturing. Fruit of 'Rem Red' amur honeysuckle matures in September to November and may remain on the plant well into winter. Planting some of all species lengthens the time that they supply food to wildlife. Direct seeding has been unsuccessful, but regeneration and spread of plants to adjacent areas does occur from seed disseminated by birds. These species initiate spring growth earlier than most other shrubs; thus, freshly dug nursery seedlings already may be growing and be susceptible to heat damage while in transit or awaiting planting.

INDIGOBUSH
(*Amorpha fruticosa*)

Type of plant: Shrub-legume
(Nitrogen-fixer)
Intermediate tolerance to shade

Origin: Native

Lower pH limit: 4.0

Elevation limit: Not above 3,000 feet

Planting materials: Seedlings (1-0), seed

Seeding rate: ½ to 1 lb/acre (seed in pods)

Time of seeding: Spring, fall, winter

Major uses: Wildlife food and cover, watershed protection

Regions where adapted: All

Comments: This woody legume is native east of the Mississippi River but has been used mostly in the Appalachian Coal Region. Plants normally grow 8 to 10 feet tall on minesoils. Similar to sumacs in growth form and appearance. Establishment usually good but plant growth fairly slow; plants may average about 2 feet in height after three growing seasons. Plants of indigobush are a good site conditioner for the invasion of other native species; they often support a lush herbaceous understory due to nitrogen-fixing capability. Unwanted spreading from seed apparently is not a problem even where annual seed production is heavy. Fruit normally ripens in August. For direct seeding, seed in pods usually are sown. Because the seeds have an impermeable seed coat and high percentage of dormant seed, germination of some of the seed will be delayed for 2 to 3 years after sowing. Special inoculum is available, but inoculating seed has not been necessary for successful establishment.

JAPAN LESPEDEZA
(*Lespedeza japonica*)
SHRUB LESPEDEZA
(*Lespedeza bicolor*)
THUNBERG LESPEDEZA
(*Lespedeza thunbergii*)

Type of plant: Shrub-legume
(Nitrogen-fixer)
Intolerant to shade

Origin: Introduced

Lower pH limit: 4.5

Elevation limit: Not above 2,500 feet

Planting materials: Seedlings (1-0), seed (scarified)

Seeding rate: 1 to 3 lb/acre

Time of seeding: Spring, late winter

Superior cultivars: 'Natob' bicolor

Major uses: Wildlife food and cover, esthetics and screening

Regions where adapted: All except northern climates

Comments: The shrub lespedezas have been extensively planted throughout the South and Southeast for wildlife food and cover; the seeds are valuable food for quail and rabbits bark the stems in winter. Mature plants are 4 to 10 feet tall. Plants in full bloom are esthetically attractive and attract honey bees. Establishment usually is most rapid and assured with planted seedlings, but also is accomplished by direct seeding. Normally, seed is mixed and sown with herbaceous species; establishment of the shrub lespedeza plants may not be obvious until the second growing season. Use standard lespedeza inoculum on seed. The classification of shrub lespedeza is difficult and confused because of hybridization among species and variants of species. Common *L. bicolor* is the most abundant and widely planted. Some taxonomic authorities consider *L. japonica* as a variant of *L. thunbergii*. 'Natob' *L. bicolor* matures seed earlier and is more winter-hardy than other cultivars of shrub lespedeza grown in the United States; it has been grown as far north as Pennsylvania and recommended for higher elevations in Central and Southern Appalachia. Seed supplies of pure species and cultivars are scarce or nonexistent.

BRISTLY LOCUST
(Robinia fertilis)
ROSE-ACACIA LOCUST
(Robinia hispida)

Type of plant: Shrub-legume
(Nitrogen-fixer)
Intolerant to shade

Origin: Native

Lower pH limit: 3.5

Planting materials: Seedlings (1-0), seed (scarified, special inoculum)

Seeding rate: 2 to 5 lb/acre

Time of seeding: Spring, fall, winter

Superior cultivars: 'Arnot' Bristly Locust

Major uses: Erosion control, wildlife cover and food

Regions where adapted: All, see note below

Comments: Bristly locust is one of the best species for erosion control on extremely acid minesoils. The plants spread primarily from root suckers that begin to form during the first growing season. Dense thickets form even on eroded sites because root suckering is stimulated where the roots are exposed by erosion. Evidence of becoming a "pest" plant is not apparent even where stands are 12 to 15 years old. Root suckering is retarded or will not occur in well-sodded areas. Usually established by planting 1-year-old seedlings at 6- by 6-foot spacing, but can also be direct seeded. Seeds must be scarified before planting. Plants grow to a height of 8 to 10 feet in about 5 years. Dense thickets of this species provide cover for wildlife. Rose-acacia locust (*Robinia hispida*) is similar to bristly locust in appearance and growth habit and has the same usefulness for vegetating surface mines. Adaptation in Southern Lignite and southwestern part of Interior is uncertain.

AUTUMN OLIVE
(Elaeagnus umbellata)

Type of plant: Shrub
(Nitrogen-fixer)
Intermediate tolerance to shade

Origin: Introduced

Lower pH limit: 4.0

Planting materials: Seedlings (1-0)

Superior cultivars: 'Cardinal'

Major uses: Wildlife food and cover, watershed protection, esthetics and screening

Regions where adapted: All

Comments: This nonleguminous species is adapted in all of the eastern coal regions; easily established on a wide range of minesoil types and conditions. Initial survival and growth usually good even where planted in an established cover of herbaceous vegetation. Growth of adjacent plants and understory grasses enhanced by its nitrogen-fixing capability. Has been used as a nurse plant with crop trees. Plants often grow to height of about 20 feet. After 3 to 4 years, they begin producing abundant fruit that is used in the fall and winter by birds and mammals. Plants also provide browse for deer. Direct seeding on minesoils usually unsuccessful but plants can be spread by dissemination of seed by birds. Has potential to become a "pest" plant and planting it has been banned in some areas. The cultivar 'Cardinal" was selected for its high fruit yield and long retention of fruit on the plant. Other shrubby species of *Elaeagnus* have been tried in some Appalachian States. Cherry olive (*E. multiflora*) and thorny olive (*E. pungens*) performed nearly as well as autumn olive on acid spoil.

FRAGRANT SUMAC
(*Rhus aromatica*)
SHINING SUMAC
(*Rhus copallina*)

Type of plant: Shrub
Shade tolerance: Shining—Intermediate
Fragrant—Tolerant

Origin: Native

Lower pH limit: Shining—4.0
Fragrant—4.5

Planting materials: Seedlings (1-0, 2-0), rooted cuttings

Major uses: Wildlife food and cover, esthetics

Regions where adapted: All

Comments: The sumacs are native to the eastern United States. They have not been tested on surface mines in all of the coal regions, but often volunteer on minesoils that are several years old; chances for success of planted seedlings seem promising. Shining sumac has shown the best growth characteristics in test plantings and spreads by seed and root suckers. Smooth sumac (*R. glabra) and staghorn sumac (R. typhina*) also show promise but were not tested as much as shining and fragrant sumacs. Suggested use is for wildlife plantings in blocks of 100 to 200 plants spaced 4 to 5 feet apart. Sumac often volunteers on abandoned spoils and is considered a pest in some agricultural land uses.

VIBURNUM
(*Viburnum* spp.)

Type of plant: Shrub

Shade tolerance: Varies by species; most are tolerant, a few intermediate.

Origin: Native

Lower pH limit: 4.0

Planting materials: Seedlings (1-0 or 2-0), rooted cuttings

Major Uses: Wildlife food and cover

Regions where adapted: All

Comments: The characteristics of viburnums make them an important genera for wildlife habitat. The dense growth form of many species provides good nesting or escape cover for small birds and mammals. Fruits are eaten by numerous birds and mammals, and the twigs, bark, and leaves are eaten by deer, rabbits, and beaver. *Viburnum dentatum*, arrowwood, has the widest distribution. Planting stock of this species would most likely be available throughout the coal regions. Other species should not be overlooked. Hobble bush, *V. alnifolium*, mapleleaf viburnum, *V. acerifolium*, and nanny berry, *V. lentago*, are more tolerant than arrowwood of acid soils. Species adapted to dry sites include withe-rod, *V. cassinoides*, and mapleleaf viburnum. Local experience and seedling availability will be the major factors influencing the use of viburnums.

Table 19. Shrub species of lesser importance or use.

Common and Scientific Name	Origin*	Lower pH Limit	Major Uses†
Blueberry (*Vaccinium* spp.)	N	4.0	H, O
Comments: Planted successfully in several areas in Appalachian Region. Grows slowly but not a hindrance to planting as cash crop. Species and varieties adapted to the local area should be selected. In wildlife plantings, provides both food and cover. Only horticultural varieties available commercially.			
Silver buffaloberry (*Shepherdia argentea*)	N	4.0	H, W
Comments: Thorny shrub 6 to 10 feet tall. Fixes nitrogen. Growth similar to that of autumn olive, but no spreading by seed noted. Field plant 2-0 seedlings. Northern Appalachian Region.			
Chokecherry (*Prunus virginiana*)	N	5.0	H
Comments: Tall shrub, 8 to 18 feet, widely adaptable. Excellent food and cover plant for wildlife. Spreads from root sprouts. Established easily from 1-0 seedlings. Potential use in all regions.			
American elder (*Sambucus canadensis*)	N	5.0	H, E
Comments: Excellent food and cover plant for wildlife, especially songbirds. Establish with 1-0 seedlings. Test plantings on mined lands are few. Potential use in all regions.			
Grape (*Vitis spp.*)	N	4.5	H, O
Comments: Grapevines can be used as component of wildlife plantings or in pure plantings to establish vineyards. Fox grape, *Vitis labrusca*, is native to the Appalachian Region and is important wildlife food. Cultivated varieties of *V. labrusca* are major component of grape culture in the Appalachian Region. Use on reclaimed land has been limited.			
Hawthorn (*Crateagus* spp.)	N	5.5	H, E
Comments: Tall shrubs; there are many hybrids and varieties. Washington hawthorn, *C. phaenopyrum*, is the most widely used and available. Field plant 1-0 seedlings. Intolerant. Potential use in all regions.			
Japanese honeysuckle (*Lonicera japonica*)	I	4.5	H
Comments: Naturalized in all eastern States. Seldom planted but often present due to natural invasion. Excellent species for wildlife habitat but can become a pest in agricultural and forestry land uses. Retains green foliage in winter. 'Halls" improved cultivar. Tolerant.			
Amur privet (*Ligustrum amurense*)	I	4.5	H, E
Comments: Naturalized in southeastern United States. Medium-size shrub. Field plant 1-0 or 2-0 seedlings. Tolerant. Successful on several minesoil plantings in Appalachian Region. Probably adapted to most of Interior and Lignite Regions.			
American plum (*Prunus americana*)	N	5.0	H, E
Comments: Recommended for wildlife plantings in most of Interior and Lignite Regions. Large shrub or small tree.			
Rugosa rose (*Rosa rugosa*)	I	5.0	H, E
Comments: Excellent food and cover plant for wildlife; survival and growth on minesoil plantings in Appalachian Region were less than desired. Intolerant.			
Western sandcherry (*Prunus besseyi*)	N	4.0	H
Comments: A 3- to 6-foot bushy shrub good for wildlife cover and food. Produces fruit in 2 to 3 years. Plant 1-0 seedings. Successful on minesoil plantings in Central and Southern Appalachian Region and southeastern Interior Region.			
Purpleosier willow (*Salix purpurea*)	I	5.0	W, H
Comments: Useful along ponds, seepage areas. Grows best in pH range 5.0 to 6.0. Adapted in most of eastern coal regions.			

*I = Introduced; N = Native.

†H = Habitat (food and cover) for wildlife; E = Esthetics and screening; W = Watershed protection (erosion control); O = Other horticulture land uses.

JAPANESE LARCH
(*Larix leptolepis*)

Type of plant: Tree-conifer
Size: Medium
Intolerant to shade

Origin: Introduced

Lower pH limit: 4.0 to 4.5

Elevation limit: Not below 3,000 feet in West Virginia

Planting materials: Seedlings (1-0, 2-0)

Major uses: Forest products (posts, mine props, and lumber), esthetics and screening

Regions where adapted: Northern Appalachian

Comments: This deciduous conifer has been used mostly in Pennsylvania and higher elevations of West Virginia. Growth is more rapid than for other conifers. However, growth rate is greatly reduced on leveled, compacted minesoils. Annual needle fall produces more ground cover than most conifers. Superior to European larch in survival, growth rate, and form. Larch initiates growth early in the spring, sometimes before seedlings can be dug in the nursery, so care should be exercised during shipment and storage to prevent heating and subsequent mortality of the seedlings.

Growth Performance: 5.4 inches dbh and 31 feet tall, averaged at three 30-year-old plantations in Pennsylvania.

EASTERN WHITE PINE
(*Pinus strobus*)

Type of plant: Tree-conifer
Size: Large
Tolerant to intermediate tolerance to shade

Origin: Native

Lower pH limit: 4.0

Planting materials: Seedlings (2-0, 3-0)

Major uses: Forest products (lumber), wildlife food and cover, Christmas trees, esthetics and screening

Regions where adapted: Northern and Central Appalachians, Interior except southwestern part

Comments: Widely planted, desirable timber species for moderately acid mine spoils. More adapted than most pine species to higher pH spoils. Growth for first few years after planting is notoriously slow but can be very fast after reaching the sapling stage. More shade tolerant and, thus, better suited than other pines for mixed plantings. Natural range is Northern and Northeastern States and Appalachian Mountains. Seedlings from North Carolina seed source should be planted south of 39th parallel. Use northern seed sources above this latitude.

Growth performance:

Location	No. Test Sites	Age (years)	Percent Survival	Dbh (inches)	Height (feet)	Basal Area (ft²/acre)
Illinois, Indiana	11	30	10	5.1	—	13
Ohio	7	30	26	8.0	42	81
Pennsylvania	2	30	*	6.1	27	—

*39 percent survival at age 10 (16 sites).

LOBLOLLY PINE
(*Pinus taeda*)

Type of plant: Tree-conifer
Size: Large
Intermediate tolerance to shade

Origin: Native

Lower pH limit: 4.0

Elevation limit: Not above 2,500 feet

Planting materials: Seedlings (1-0), seed (stratified, bird and rodent repellent)

Seeding rate: 1 to 1½ lb/acre

Time of seeding: Spring (stratified seed), late fall-early winter (unstratified seed)

Major uses: Forest products (pulp, poles, lumber), esthetics and screening, wildlife cover and food

Regions where adapted: Southern and Central Appalachian, southern part of Interior, Lignite

Comments: Fast-growing southern pine adapted to wide range of minesoil types. Natural range is southward from central Arkansas and southern Tennessee, yet often planted and usually thrives several hundred miles north of this range. However, natural reproduction and success of direct seeding diminishes outside of natural range. Trees are vulnerable to damage from ice and heavy snow and cannot withstand prolonged periods of subzero temperatures. Only ecotypes from the northern part of its natural range should be used in the northern-most plantings. Growth rate of loblolly can be improved by planting with a legume such as Kobe, Korean, or sericea lespedeza, or by planting in alternate rows with European alder.

Growth performance:

Location	No. Test Sites	Age (years)	Percent Survival	Dbh (inches)	Height (feet)	Basal Area (ft²/acre)
Mo., Kans., Okla.	8	30	21	9.8	43	98
Illinois, Indiana	11	30	15	7.6	—	42
Western Kentucky	1	20	28	5.0	37	34
Tennessee Valley	19	8 to 22	—	5.4	34	—
Eastern Kentucky	1	10	52	3.9	21	38
Eastern Kentucky	1	18	—	9.2	50	190

PITCH PINE
(*Pinus rigida*)

Type of plant: Tree-conifer
Size: Medium
Intolerant to shade

Origin: Native

Lower pH limit: 4.0

Elevation limit: Not above 3,000 feet

Planting materials: Seedlings (1-0)

Major uses: Esthetics and screening, wildlife cover and food, forest products (pulp and lumber)

Regions where adapted: Appalachian

Comments: Similar to Virginia pine in adaptation, site requirements, and uses. Has better esthetic and wood qualities than Virginia pine. Especially useful for extremely acid and relatively dry sites that are not suitable for more valuable tree species. Often planted in mixtures with other pines, but normally not with hardwoods. Poor survival in most test plantings in Interior Region.

Growth performance:

Location	No. Test Sites	Age (years)	Percent Survival	Dbh (inches)	Height (feet)	Basal Area (ft²/acre)
Missouri	4	30	1	7.6	25	1
Kansas	4	30	16	6.6	31	34
Illinois, Indiana	11	30	6	5.3	—	8
Ohio	1	30	34	6.5	37	70
Eastern Kentucky	1	10	93	3.4	16	52
Eastern Kentucky	1	18	—	5.6	35	142
Western Kentucky	1	20	25	5.4	30	35
Pennsylvania	4	30	*	4.7	23	—

*36 percent survival at age 10 (18 sites).

RED PINE

(*Pinus resinosa*)

Type of plant: Tree-conifer
Size: Medium
Intermediate tolerance to shade

Origin: Native

Lower pH limit: 4.0 to 4.5

Elevation limit: Not below 2,200 feet in West Virginia

Planting materials: Seedlings (2-0, 3-0)

Major uses: Forest products (pulp, poles and lumber), esthetics and screening, wildlife cover and food, Christmas trees

Regions where adapted: Northern Appalachian

Comments: An attractive tree that has performed well on a variety of minesoils, especially in the Northern Appalachian Region. Highly susceptible to European pine shoot moth, it should not be planted in areas that have a high incidence of this insect. Can be used for Christmas trees and is excellent for screening. Has been successful in alternate row plantings with hybrid poplar in Pennsylvania. Natural range is northernmost States.

Growth performance:

Location	No. Test Sites	Age (years)	Percent Survival	Dbh (inches)	Height (feet)	Basal Area (ft²/acre)
Illinois, Indiana	11	30	8	4.3	—	7
Ohio	6	30	20	7.2	36	50
Pennsylvania	2	30	*	7.3	29	—

*49 percent survival at age 10 (8 sites).

SCOTCH PINE

(*Pinus sylvestris*)

Type of plant: Tree-conifer
Size: Medium
Intolerant to shade

Origin: Introduced

Lower pH limit: 4.0

Planting materials: Seedlings (2-0, 3-0)

Seedling spacing: 5 × 5 feet or 6 × 6 feet (for Christmas trees)

Major uses: Christmas trees, esthetics and screening, wildlife cover and food, forest products (pulp and lumber)

Regions where adapted: Appalachian, Interior (except southwestern most part)

Comments: Most widely planted introduced tree species in the United States. It is the pine with the greatest natural range and it grows in many different ecological situations. Sources differ in many characteristics, such as seed size, tree color, form and susceptibility to heat, cold, and drought. Planted widely for Christmas trees both on and off mined sites. Seed source is important because some Scotch pine turn yellow in the fall. Has been used in reforestation but has reputation for crooked stem. Choice of seed source is important to avoid this characteristic. Not recommended for use in Southern Lignite Region.

SHORTLEAF PINE
(*Pinus echinata*)

Type of plant: Tree-conifer
Size: Medium
Intermediate tolerance to shade

Origin: Native

Lower pH limit: 4.5

Planting materials: seedlings (1-0, 2-0), seed (stratified, insect and rodent repellent)

Seeding rate: ½ to 1 lb/acre

Time of seeding: Spring (stratified seed), late fall-early winter (unstratified seed)

Major uses: Forest products (pulp, poles, mine timbers, building materials), wildlife cover and food, esthetics and screening

Regions where adapted: Southern and Central Appalachians, southern part of Interior, Lignite

Comments: Adapted to variety of mined sites, but not recommended in minesoils above pH 6.0. Often competes poorly where interplanted with hardwood species that will overtop it. Generally should be planted in pure stands or can be mixed with other pines. Growth was increased where interplanted with European alder. Young trees often subject to damage by pine tip moth, but usually recover. Natural range similar to loblolly pine.

Growth performance:

Location	No. Test Sites	Age (years)	Percent Survival	Dbh (inches)	Height (feet)	Basal Area (ft^2/acre)
Mo., Kans., Okla.	8	29	23	6.6	33	49
Illinois, Indiana	11	30	6	5.0	—	7
Ohio	1	30	11	5.1	34	14
Indiana	1	35	—	8.1	50	190
Tennessee Valley	13	14 to 25	—	3.9	29	—
Eastern Kentucky	1	10	75	3.7	19	50

VIRGINIA PINE
(*Pinus virginiana*)

Type of plant: Tree-conifer
Size: Small
Intolerant to shade

Origin: Native

Lower pH limit: 3.5 to 4.0

Elevation limit: Not above 2,500 feet in West Virginia

Planting materials: Seedlings (1-0), seed (stratified, insect and rodent repellent)

Seeding rate: ¼ to ½ lb/acre

Time of seeding: Spring (stratified seed), late fall-early winter (unstratified seed)

Major uses: Esthetics and screening, wildlife cover and food, forest products (pulp), Christmas trees

Regions where adapted: Appalachian, Interior

Comments: Planted widely on minesoils throughout the eastern United States, even in the Interior Coal Region which is outside its natural range. Adapted to wide range of minesoil types and especially useful for vegetating acid and droughty sites. Within its natural range, often a pioneer species on minesoils and other disturbed lands. Direct seeding sometimes successful, but chances of success are less than for planting nursery seedlings. Valuable for wildlife cover and food, especially when planted in blocks or strips that alternate with herbaceous and other woody species. Use identified seed sources for Christmas tree plantings.

Growth performance:

Location	No. Test Sites	Age (years)	Percent Survival	Dbh (inches)	Height (feet)	Basal Area (ft^2/acre)
Mo., Kans., Okla.	8	30	20	6.5	30	41
Illinois, Indiana	11	30	11	7.0	—	26
Western Kentucky	1	20	27	5.3	30	37
Tennessee Valley	3	12	—	3.9	25	—
Eastern Kentucky	2	10	84	3.4	20	47
Eastern Kentucky	1	18	—	6.0	43	221

EASTERN REDCEDAR
(*Juniperus virginiana*)

Type of Plant: Tree-conifer
Size: Small
Intolerant to shade

Origin: Native

Lower pH limit: 5.0

Planting materials: Seedlings (1-0, 2-0)

Major uses: Wildlife cover and food, esthetics and screening, forest products (fenceposts, Christmas trees)

Regions where adapted: Interior, Southern Lignite

Comments: Commonly believed to be associated primarily with limestone-derived soils, performs best on calcareous and mildly acid minesoils. However, soil acidity may be no more critical than other soil conditions or the presence of competing woody vegetation. In Illinois, appeared suited for most mined-land conditions except those with unstable sandy surfaces. Trees in 30-year-old plantings were being shaded out by planted and volunteer hardwoods. Probably best suited for use in Western Interior and Lignite Regions. Spreads by seed. Limit or avoid use where spreading may interfere with proposed land use.

Growth performance:

Location	No. Test Sites	Age (years)	Percent Survival	Dbh (inches)	Height (feet)	Basal Area (ft^2/acre)
Mo., Kans., Okla.	9	30	22	5.0	27	27
Illinois, Indiana	11	30	22	4.4	—	21
Iowa	3	8	39	—	5	—

NORWAY SPRUCE
(*Picea abies*)
WHITE SPRUCE
(*Picea glauca*)

Type of plant: Tree-conifer
Size: White—Medium
Norway—Large
Tolerant to shade

Origin: White—Native
Norway—Introduced

Lower pH limit: 4.5 to 5.0

Elevation limit: Not below 2,500 feet in West Virginia and eastern Kentucky

Planting materials: Seedlings (2-0, 3-0)

Major uses: Wildlife cover and food, esthetics and screening, forest products (pulp, musical instruments, and lumber), Christmas trees

Regions where adapted: Northern Appalachian

Comments: Spruce occur naturally in northern temperate regions. Use is recommended primarily in the northern Appalachians and at the higher elevations of the central Appalachians. Because they are less adapted than pines to dry, low-fertility sites, spruce should be planted on better quality minesoil and on cool, moist sites. Growth is slow for the first few years, but growth rate usually increases after this period. Because they are shade tolerant, spruce persist at a reduced growth rate in the understory of other woody species. In West Virginia, the growth of spruce interplanted with autumn olive was very slow for the first 3 to 4 years, but by age 10 the spruce were matching or exceeding the height of the autumn olive. Spruce are valuable for providing winter shelter for some species of wildlife and they are widely used for shelterbelts, screening, and esthetic purposes.

EUROPEAN BLACK ALDER
(*Alnus glutinosa*)

Type of plant: Tree-hardwood
(Nitrogen-fixer)
Size: Medium
Intolerant to shade

Origin: Introduced

Lower pH limit: 3.5 to 4.0

Planting materials: Seedlings (1-0)

Major uses: Esthetics and screening, forestry (nurse tree, site improvement, and pulp), wildlife cover and food

Regions where adapted: Northern and Central Appalachian, Interior except southern-most part

Comments: Nitrogen-fixing (nonlegume) tree adapted to wide range of minesoil types except droughty situations. Good early survival and rapid growth in most areas. Especially valuable on acid minesoils in cooler climates. Alder plantings have persisted for more than 20 years in northern regions, but in eastern Kentucky began to die back at 10 years. Longevity in southern climates uncertain. Growth rate of hardwoods and pines can be increased by interplanting with black alder; plant alder in every other row or every third row.

CRAB APPLE
(*Malus* spp.)

Type of plant: Tree (or large shrub)-hardwood
Size: Small
Intolerant to shade

Origin: Introduced

Lower pH limit: 4.5

Planting materials: Seedlings (1-0)

Major uses: Wildlife food and cover, esthetics

Regions where adapted: Appalachian, Interior

Comments: Classified as a shrub in some literature. Several introduced species and horticultural varieties have been established successfully, including Siberian crab apple (*M. baccata*), Japanese flowering crab apple (*M. floribunda*), tea crab apple (*M. hupehensis*), toringo crab apple (*M. sieboldii*), and others not identified. These have been tested on numerous sites mostly in the Appalachian Region but probably are adapted in most of the coal-mining States. Highly successful for revegetating abandoned spoils in Tennessee. Planted primarily for wildlife habitat and esthetic purposes. Usually produces an abundant crop of fruit. Recommend planting in small scattered blocks or on a 20- by 20-foot spacing over larger areas. Seedlings are especially susceptible to deer browsing and rodent damage.

GREEN ASH
(*Fraxinus pennsylvanica*)

Type of plant: Tree-hardwood
Size: Medium
Intermediate tolerance to shade

Origin: Native

Lower pH limit: 4.0

Elevation limit: Not above 2,500 feet

Planting materials: Seedlings (1-0)

Major uses: Wildlife food and cover, forest products (pulp, tool handles, and baseball bats)

Regions where adapted: All

Comments: Has been planted widely on surface mines and has consistently provided good initial and long-term survival. But growth generally has been poor compared with most other hardwood species. Best growth is on moist sites in minesoils containing a relatively high proportion of soil-size (< 2mm) material. Ash should be planted in mixtures with other hardwoods. Trees of this species often have poorly formed trunks that detract from their value. Native in nearly all of eastern United States.

Growth performance:

Location	No. Test Sites	Age (years)	Percent Survival	Dbh (inches)	Height (feet)	Basal Area (ft²/acre)
Mo., Kans., Okla.	9	30	33	3.8	28	23.0
Illinois, Indiana	11	30	53	4.7	—	56.8
Ohio	4	30	55	4.0	27	42.7
Pennsylvania	2	30	*	2.5	15	—

*69 percent survival at age 10 (15 sites).

WHITE ASH
(*Fraxinus americana*)

Type of plant: Tree-hardwood
Size: Medium
Intermediate tolerance to shade

Origin: Native

Lower pH limit: 4.0

Elevation limit: Not above 3,000 feet

Planting materials: Seedlings (1-0)

Major uses: Forest products (pulp, veneer, lumber, tool handles, and baseball bats), wildlife food and cover

Regions where adapted: All

Comments: Long-term survival on surface mines is relatively good but growth usually is slower than for other hardwoods. Has not been planted as extensively as green ash. Native in all eastern coal regions but not tested on surface mines in all States. Should be planted in mixtures with other hardwoods. Direct-seeding trials generally produced poor results. A valuable forest species, its trunk usually is long, straight, clear, and cylindrical.

Growth performance:

Location	No. Test Sites	Age (years)	Percent Survival	Dbh (inches)	Height (feet)	Basal Area (ft²/acre)
Ohio	4	30	45	5.0	36	55
Pennsylvania	2	30	*	2.5	19	—

*65 percent survival at age 10 (13 sites).

RIVER BIRCH
(*Betula nigra*)

Type of plant: Tree-hardwood
Size: Medium
Intolerant to shade

Origin: Native

Lower pH limit: 4.0

Planting materials: Seedlings (1-0)

Major uses: Esthetics and screening, wildlife food and cover, forest products (furniture, cabinets, crates)

Regions where adapted: All

Comments: The only southern species of birch. Grows naturally on banks of rivers, streams, ponds, and swamps where soil may be flooded for part of the year. Suited for poorly drained acid minesoils and should be used primarily where soil is too acid for most other hardwoods. Trees usually have poor form. In some areas, trees found growing on the more acid spoils were taller, and had better form and fewer multiple stems than trees on the less acid sites where ground cover was greatest. Adapted climatically to most regions except northern-most Appalachian. Plant in mixture with other hardwoods. May have greatest potential for reclaiming remined areas and abandoned mine sites.

BLACK CHERRY
(*Prunus serotina*)

Type of plant: Tree-hardwood
Size: Medium
Intermediate tolerance to shade

Origin: Native

Lower pH limit: 4.5

Planting materials: Seedlings (1-0)

Major uses: Forest products (furniture and veneer), wildlife food

Regions where adapted: All

Comments: Native in most of eastern United States, but most of the experimental plantings of this species have been made in Missouri, Kansas, and Oklahoma, where growth performance was similar to that of other hardwoods. Good early survival in Pennsylvania and West Virginia plantings, but development and growth usually prevented by deer browsing. Attempts at establishment by direct seeding have failed, yet black cherry often is one of the more abundant volunteer species on naturally and artificially reforested surface mines. Grows best on moist sites and is somewhat tolerant of competition. Should be planted in a mixture with other hardwoods.

Growth performance: In Missouri, Kansas, and Oklahoma, 30-year-old plantings at nine sites averaged 22 percent survival, 5.2 inches dbh, 36 feet in height, and 29 ft^2/acre basal area.

CHINESE CHESTNUT
(*Castanea mollissima*)

Type of plant: Tree-hardwood
Size: Medium
Intermediate tolerance to shade

Origin: Introduced

Lower pH limit: 4.5

Planting materials: Seedlings (1-0)

Major uses: Wildlife food and cover, nut orchards

Regions where adapted: Appalachian, Eastern Interior

Comments: An exotic species that has been planted in an attempt to replace the native American chestnut. The commercial value of its wood is uncertain. It has been planted mostly for nut production and as an ornamental. Four superior strains have been selected for the quality of their nuts and are propagated for orchard purposes. Has performed fairly well in test plantings on surface mines, especially on sites with moderately good exposure and minesoil quality (pH 5.0 to 7.0). For surface-mine reclamation, its value appears greatest for use in wildlife habitat plantings. In 20- to 30-year-old plantings in Indiana, some of the trees in stands with closed canopies are changing from an orchard-form to a timber-form characteristic. Natural reproduction was observed in stands more than 12 to 15 years old.

EASTERN COTTONWOOD
(*Populus deltoides*)

Type of plant: Tree-hardwood
Size: Large
Intolerant to shade

Origin: Native

Lower pH limit: 4.5

Elevation limit: Not above 2,500 feet

Planting materials: Seedlings (1-0), cuttings

Seedling spacing: 8 x 8 feet or greater

Major uses: Forest products (pulp, lumber, and veneer)

Regions where adapted: All except northern-most Appalachian and higher elevations

Comments: This rapid-growing bottomland species has been planted widely on minesoils and survived and grown surprisingly well even on some upland mined sites in Central and Southern Appalachian Region. Also has been common volunteer on minesoils throughout the Interior Coal Region. Is native in all of the Interior and Lignite Regions. Long-term growth and development is best on moist, well-drained soils. Where considered for commercial use, recommend planting in blocks or in bands of several rows in mixtures with other hardwoods. Interplanting with European black alder has increased height of cottonwood by 30 percent and dbh by 20 percent after 10 years of growth.

Growth performance: Volunteer trees that are 30 to 35 years old often attain height of 65 to 70 feet and dbh of 12 to 15 inches. Planted cottonwood in Illinois and Indiana averaged 11 inches dbh and 104 ft^2/acre basal area at age 30.

BLACK LOCUST
(Robinia pseudoacacia)

Type of plant: Tree-hardwood (Nitrogen-fixer)
Size: Medium
Intolerant to shade

Origin: Native

Lower pH limit: 4.0

Elevation limit: Not above 3,000 feet

Planting materials: Seedlings (1-0), seed (scarified)

Seeding rate: 1 to 3 lb/acre (in mixture with herbaceous species)

Time of seeding: Spring, fall, winter

Major uses: Site improvement (nurse tree with hardwoods), wildlife food and cover, fenceposts, fuel, watershed protection

Regions where adapted: All

Comments: Most frequently and widely used tree for surface-mine plantings; adapted to a wide range of minesoil types. Established easily by direct seeding and planted seedlings. Provides quick overstory cover due to rapid growth. Phosphorus fertilizer benefits seedling growth, especially where direct seeded. Spreads by root sprouting and seed. Susceptible to damage by locust borer that may cause trees to die 10 to 20 years after planting. Surviving healthy trees can be cut for fenceposts. Locust seed is prime quail food in some areas. Use as a "nurse" tree is controversial. Locust improves a site for growth of other trees, especially for natural invasion of hardwoods; but its thorny branches can physically damage leaders and bark of smaller, slower growing adjacent trees. Locust should make up no more than 25 to 33 percent of a planted hardwood mix.

Growth performance:

Location	No. Test Sites	Age (years)	Percent Survival	Dbh (inches)	Height (feet)	Basal Area (ft²/acre)
Mo., Kans., Okla.	10	30	35	6.1	42	63
Illinois, Indiana	11	30	36	6.4	—	72
Ohio	7	30	24	5.9	36	41
Western Kentucky	1	20	50	4.6	36	51
Tennessee Valley	7	11 to 19	—	4.4	39	—

RED MAPLE
(Acer rubrum)
SILVER MAPLE
(Acer saccharinum)

Type of plant: Tree-hardwood
Size: Medium
Intermediate tolerance to shade

Origin: Native

Lower pH limit: 4.0 to 4.5

Planting materials: Seedlings (1-0)

Major uses: Forest products (pulp, lumber, and veneer), wildlife food

Regions where adapted: All except as noted below

Comments: These maples, collectively called soft maples, are relatively fast growing. Adapted to a range of minesoil conditions—from fairly wet to dry, fine and coarse-textured, and pH 4.0 to 7.0—but grow best on loamy soils with good drainage. Both species usually reproduce by natural seeding. Pure stands of red maple can produce a dense canopy that inhibits growth of understory vegetation. Silver maple often are multistemmed. Neither species considered high-quality hardwood. Plant in mixtures with other hardwoods. Both species native to most of eastern coal regions except silver maple in Lignite Region and red maple in northwestern part of Interior Region.

Growth performance:

Location	No. Test Sites	Age (years)	Percent Survival	Dbh (inches)	Height (feet)	Basal Area (ft²/acre)
RED MAPLE						
Indiana	4	28	—	6.0	47	60
Eastern Kentucky	1	18	—	5.7	43	72
SILVER MAPLE						
Illinois, Indiana	11	30	29	5.1	—	37
Ohio	1	30	26	5.7	35	41

SUGAR MAPLE
(*Acer saccharum*)

Type of plant: Tree-hardwood
Size: Medium
Tolerant to shade

Origin: Native

Lower pH limit: 4.5

Planting materials: Seedlings (1-0, 2-0)

Major uses: Forest products (lumber and veneer), wildlife food and cover

Regions where adapted: Northern and Central Appalachian, Eastern Interior

Comments: Also called hard maple, has not been planted widely on surface-mined lands. Yet it could be one of the more valuable species for planting in mixtures with other hardwoods. Grows best on moist but well-drained minesoils with predominantly loamy texture and pH 5.5 to 7.5. Initial growth is slow. In western Kentucky, sugar maple was more successful planted in mixture with black locust than in pure stands. At 10 years, the best survival and growth occurred on lower slopes and well-drained bottoms where many of the maples had single, straight, and well-formed stems. In pure stands and on ridges and upper slopes, more than one-half of the trees had multiple stems.

BUR OAK
(*Quercus macrocarpa*)

Type of plant: Tree-hardwood
Size: Large
Intermediate tolerance to shade

Origin: Native

Lower pH limit: 4.0

Planting materials: Seedlings (1-0, 2-0), seed (acorns)

Seeding rate: 2 or 3 acorns per planting spot

Time of seeding: Fall

Major uses: Forest products (rough lumber, barrel staves, flooring, railroad ties, and pulp), wildlife food (acorns)

Regions where adapted: Interior, Lignite, and Central Appalachian except as noted below

Comments: One of the better performing hardwoods in surface-mine plantings in Missouri, Kansas, and Oklahoma. Established successfully from both seedlings and seed. Grows on a variety of minesoil types. Reportedly one of the most drought-resistant oaks and performs well on exposed sandy sites. Tolerates competition from herbaceous cover and grows well in mixture with black locust and other species. Acorns of bur oak have no seed dormancy and germinate almost immediately after falling. Collect acorns immediately after they have fallen and plant in the fall. Plant acorns ½ to 1 inch deep, using two or three per seeding spot to increase chances of getting a fully stocked stand. Space the seeding spots the same as for planted seedlings. Native in all of Interior Coal Region and western part of Lignite. Some successful plantings in Ohio and eastern Kentucky.

Growth performance:

Location	No. Test Sites	Age (years)	Percent Survival	Dbh (inches)	Height (feet)	Basal Area (ft^2/acre)
DIRECT SEEDED						
Mo., Kans., Okla.	10	30	24	4.8	28	27
Ohio	3	30	37	5.8	33	60
PLANTED SEEDLINGS						
Mo., Kans., Okla.	9	30	39	5.0	29	47

NORTHERN RED OAK
(*Quercus rubra*)

Type of plant: Tree-hardwood
Size: Medium
Intermediate tolerance to shade

Origin: Native

Lower pH limit: 4.0

Planting materials: Seedlings (1-0)

Major uses: Forest products (lumber, veneer, and pulp), wildlife food and cover

Regions where adapted: Appalachian, Eastern Interior

Comments: Has relatively slow early growth, but growth rate increases as trees reach sapling size. Has been one of the better performing hardwoods. Performs best on moist sites on minesoils with high percentage of soil-size (< 2mm) particles. As with many hardwoods, young seedlings subject to damage from rodents and deer. Can be planted in pure stands, but planting in mixtures with other hardwoods is recommended. Direct-seeding trials have produced mixed results, but most have been unsatisfactory. Rodent pilferage often claims much of the seed.

Growth performance:

Location	No. Test Sites	Age (years)	Percent Survival	Dbh (inches)	Height (feet)	Basal Area (ft²/acre)
Illinois	2	35	—	9.8	72	137
Ohio	3	30	14	5.7	33	22
Pennsylvania	5	30	*	5.3	37	—
Eastern Kentucky	1	18	—	4.1	34	72†

* 62 percent survival at age 10 (9 sites).
† Basal area of mixed hardwood planting in which northern red oak is present.

SAWTOOTH OAK
(*Quercus acutissima*)

Type of plant: Tree-hardwood
Size: Small
Intermediate tolerance to shade

Origin: Introduced

Lower pH limit: 4.0

Planting materials: Seedlings (1-0)

Major uses: Wildlife food and cover, forest products (pulp)

Regions where adapted: Appalachian, see note below

Comments: This naturalized oak is an excellent species for wildlife plantings. Heavy mast crops are produced at regular frequency and at an early age. Has survived well in test plantings throughout the Appalachian Region. Was highly successful in plantings on abandoned acid spoils in Tennessee Valley Region. Probably adapted to at least the eastern part of Interior Coal and Southern Lignite Regions, but use is not documented. Pulp and fuelwood are known forest products. In a forest situation, small sawlogs for lumber are a possibility.

OSAGE-ORANGE
(*Maclura pomifera*)

Type of plant: Tree-hardwood
Size: Small
Intermediate tolerance to shade

Origin: Native

Lower pH limit: 4.5

Planting materials: Seedlings (1-0)

Major uses: Wildlife food and cover, hedgerows and screening, forest products (posts)

Regions where adapted: Interior, western part of Lignite

Comments: A small tree native to a small area of eastern Texas, southeastern Oklahoma, and southwestern Arkansas, but has been widely planted and naturalized in many eastern States. Adapted to most surface-mine conditions but performs best on the less acid and well-drained minesoils. In Illinois, initial mortality of planted seedlings was high, but subsequent survival has remained about the same. Has relatively little value as a forest species. Has been planted mostly for hedgerows and windbreaks, and cut mainly for fenceposts. Provides good cover and food for wildlife and could be planted along edges as a screen or barrier.

Growth performance:

Location	No. Test Sites	Age (years)	Percent Survival	Dbh (inches)	Height (feet)
Illinois, Indiana	11	30	33	4.4	—
Ohio	2	30	39	3.1	20

HYBRID POPLARS
(*Populus* spp.)

Type of plant: Tree-hardwood
Size: Medium
Intolerant to shade

Origin: Crosses of several native and introduced species

Lower pH limit: 4.0 to 4.5

Planting materials: Rooted cuttings, unrooted cuttings (8 to 10 inches long)

Spacing: 8- x 8-foot minimum

Major uses: Esthetics and screening, forest products (pulp and lumber)

Regions where adapted: Northern and Central Appalachian, Interior except southwestern part

Comments: Major assets are good survival and rapid growth. Greatest use has been in Pennsylvania. Best performing clones in one region may not be the best in another region. Cuttings can be taken from established hybrid poplar trees. For planting, select trees that have performed well, and make cuttings from the previous year's growth in late winter or early spring before sap starts to rise. Select branches that are between three-eighths and three-quarters of an inch in diameter and cut into pieces 8 to 10 inches long. Cover cuttings with damp sawdust and store in cool place until ends of cuttings callous over and buds start to swell. Plant cuttings vertically with buds pointing up so that at least one or two buds are above ground (usually about 1 to 2 inches of cutting above ground). Poplars can be planted in alternate rows with conifers (except larch).

Growth performance:

Location	No. Test Sites	Age (years)	Percent Survival	Dbh (inches)	Height (feet)	Basal Area (ft^2/acre)
Eastern Kentucky	1	9	95	3.1	27	44
Pennsylvania	8	10	45	5.4	31	64
Pennsylvania	2	30	—	9.0	63	—

YELLOW-POPLAR
(*Liriodendron tulipifera*)

Type of plant: Tree-hardwood
Size: Large
Intolerant to shade

Origin: Native

Lower pH limit: 4.5

Elevation limit: Not above 3,000 feet

Planting materials: Seedlings (1-0)

Major uses: Forest products (pulp, lumber, and veneer), wildlife food and cover

Regions where adapted: Appalachian, southeastern part of Interior

Comments: Results (survival) with this valuable forest species have been variable on surface-mined lands, but either total failure or good survival is rare. Performs best on fine-loamy minesoils that have fair to good drainage and pH 5.0 to 7.0. Should be planted in mixtures with other hardwoods. The trunk is tall, straight, and usually free of side branches. The flowers are an excellent source of nectar for honey bees. Also called tulip-poplar and tuliptree.

Growth performance:

Location	No. Test Sites	Age (years)	Percent Survival	Dbh (inches)	Height (feet)	Basal Area (ft²/acre)
Illinois, Indiana	11	30	7	7.6	—	20
Ohio	10	30	19	8.7	45	69
Western Kentucky	1	20	24	3.5	33	14
Eastern Kentucky	1	18	—	6.4	50	72†
Illinois	1*	22	—	8.1	58	—
Illinois	1*	30	23	8.4	60	79

*Planted under decadent black locust.
†Mixed hardwood planting in which yellow-poplar is present.

SWEETGUM
(*Liquidambar styraciflua*)

Type of plant: Tree-hardwood
Size: Large
Intolerant to shade

Origin: Native

Lower pH limit: 4.0

Elevation limit: Not Above 2,500 feet

Planting materials: Seedlings (1-0)

Major uses: Forest products, (pulp, veneer, plywood, interior parts of furniture, lumber), wildlife food and cover

Regions where adapted: Central and Southern Appalachian, Lignite, southeastern Interior

Comments: Survival of planted seedlings of this commercial hardwood has been erratic among areas. Early growth of seedlings is relatively slow, but later growth is rapid. In older plantings, many of the surviving trees have good form and size. Growth is best in fine loam minesoils on moist sites. In Illinois, growth was better on minesoils in the 4.0 to 5.0 pH range than at higher pHs. Planting sweetgum in a mixture with other valuable hardwoods such as tulip-poplar and northern red oak is recommended. Growth was increased where interplanted with European alder.

Growth performance:

Location	No. Test Sites	Age (years)	Percent Survival	Dbh (inches)	Height (feet)	Basal Area (ft²/acre)
Illinois, Indiana	11	30	27	6.4	—	54
Oklahoma	1	30	2	12.8	60	16
Eastern Kentucky	1	10	65	1.7	15	—

AMERICAN SYCAMORE
(*Platanus occidentalis*)

Type of plant: Tree-hardwood
Size: Large
Intolerant to shade

Origin: Native

Lower pH limit: 4.0 to 4.5

Elevation limit: Not above 2,500 feet

Planting materials: Seedlings (1-0)

Major uses: Forest products (pulp, lumber, and veneer)

Regions where adapted: All

Comments: Planted widely on eastern mine sites. Makes rapid growth, especially on moist sites. Dieback may occur at higher elevations in the Appalachian Region. Does not establish satisfactorily in dense herbaceous or shrubby cover. Often establishes by natural seeding on mined areas. For commercial harvest, plant in pure blocks, or in multiple row mixtures with other hardwoods.

Growth performance:

Location	No. Test Sites	Age (years)	Percent Survival	Dbh (inches)	Height (feet)	Basal Area (ft^2/acre)
Missouri	3	29	15	9.1	48	60
Kansas	3	29	26	5.2	38	34
Oklahoma	1	29	7	8.2	46	23
Western Kentucky	1	20	41	3.8	33	29
Eastern Kentucky	3	10	62*	1.7	17	—
Eastern Kentucky	1	18	—	5.9	50	72†

*5-year survival.
†Mixed hardwood planting in which sycamore is present.

BLACK WALNUT
(*Juglans nigra*)

Type of plant: Tree-hardwood
Size: Large
Intolerant to shade

Origin: Native

Lower pH limit: 5.5

Planting materials: Seedlings (1-0), seed (stratified for spring seeding)

Seeding rate: 2 or 3 seeds (nuts) per spot

Time of seeding: Fall (unstratified seed), spring (stratified seed)

Major uses: Forest products (veneer, furniture, gunstocks, novelties), wildlife food

Regions where adapted: All, see note below

Comments: Has performed best in Indiana, Illinois, and Missouri on moist sites on ungraded minesoils that were slightly acid to slightly calcareous (pH 6.0 to 7.5). Establishment was successful from both seedlings and seed. Survival and growth generally have been poor in the Appalachian Region and on acid, droughty minesoils. Although initial growth is relatively slow, can develop into a valuable forest product. Nuts are a cash crop in some localities. For a timber crop, plant in mixtures with other hardwoods. For spring seeding, nuts should be stratified outdoors over winter in moist sand, or refrigerated in plastic bags, moist peat, or sand at 34° to 41°F for 90 to 120 days. Native in most of Eastern Coal Regions.

Growth performance:

Location	No. Test Sites	Age (years)	Percent Survival	Dbh (inches)	Height (feet)	Basal Area (ft^2/acre)
DIRECT SEEDED						
Mo., Kans., Okla.	9	30	13	4.8	32	15
Illinois, Indiana	11	30	30	6.1	—	54
Ohio	5	30	4	4.1	32	3
PLANTED SEEDLINGS						
Illinois, Indiana	11	30	21	5.2	—	28
Western Kentucky	1	20	25	2.8	21	9
Illinois	1*	30	42	7.3	—	108

*Planted under decadent black locust.

Table 20. Tree species of lesser importance or use.

Common and Scientific Name	Origin*	Tolerance†	Lower pH Limit	Major Uses‡
		CONIFERS		
Baldcypress *(Taxodium distichum)*	N	M	5.0	F,H
Comments: Deciduous. Most often associated with sites where water stands for several months of the year. Has been used on both poorly and well-drained mine spoils in southern Illinois and Indiana, western Kentucky, Missouri, and Oklahoma. Natural range includes most of Lignite Region.				
Douglas-fir *(Pseudotsuga* spp.)	N	T	4.0	F,E,H,C
Comments: Western species used only in Pennsylvania. Proper seed source important for success in East. Popular Christmas tree species.				
Fraser fir *(Abies fraseri)*	N	M	5.0	C,E,H
Comments: Limited to high elevations in northern part of Southern Appalachian Region and to cool, moist sites. Plant 2-0 or 3-0 seedlings.				
European larch *(Larix decidua)*	I	I	5.0	F
Comments: Deciduous. For northern Appalachians and high elevations. Less successful than Japanese larch.				
Austrian pine *(Pinus nigra)*	I	M	4.0	E,H,C,F
Comments: Similar to native red pine in growth appearance and climatic adaptation. Has not been widely planted on minesoils but has performed well in some areas of the Northern Appalachian and Interior Regions. Used mainly for shelterbelts in the Midwest and for ornamental and esthetic purposes.				
Jack pine *(Pinus banksiana)*	N	I	4.0	H,C,F
Comments: Use in Northern Appalachian and northern half of Interior Region in pure or mixed-pine plantings. Adapted to acid, dry, and sandy soil conditions.				
Longleaf pine *(Pinus palustris)*	N	I	4.5	F,H,E
Comments: Plant only in southern part of Southern Appalachian Region and Southern Lignite Region. Plant or seed in pure stands. Well suited on spoils where surface soil is not replaced.				
Pitch X loblolly hybrid pine *(Pinus rigida X P. taeda)*	N	I	4.0	F,E,H
Comments: Experimentally planted only in Central Appalachian Region. Early growth is faster than that of either parent. Research underway to increase planting material.				
Slash pine *(Pinus elliottii)*	N	M	4.5	F,H,E
Comments: Plant or direct seed in pure stands. For use in southern half of Southern Appalachian Region.				

*I = Introduced; N = Native.

†H = Habitat (food and cover) for wildlife; E = Esthetics and screening; W = Watershed protection (erosion control); O = Other horticulture land uses.

Table 20. Tree species of lesser importance or use.

Common and Scientific Name	*Origin**	*Tolerance†*	*Lower pH Limit*	*Major Uses‡*
		HARDWOODS		
Bigtooth aspen *(Populus grandidentata)*	N	I	4.0	H,F
Comments: Will not reproduce in shade. Plant in pure blocks. For use in northern latitudes and higher elevations in Appalachia.				
European white birch *(Betula pendula)*	I	I	3.5-4.0	F,H,E
Comments: Planted successfully on acid minesoils in Pennsylvania and eastern Kentucky. Longevity not known. Use recommended only on difficult sites not suited for higher value native species.				
Gray birch *(Betula populifolia)*	N	I	3.5	E,H
Comments: For northern Appalachians and high altitudes. Similar to European white birch.				
Paper birch *(Betula papyrifera)*	N	I	3.5	F,E,H
Comments: For northern Appalachians and high altitudes.				
Sweet birch *(Betula lenta)*	N	I	4.0	H,F
Comments: Early pioneer on barren acid spoils. Promising species for planting abandoned lands and as associate with forestry plantings on current-mined lands, but practical experience lacking. Appalachian Region.				
Catalpa *(Catalpa* spp.)	N	M	5.0	E,F
Comments: Mineland plantings are mostly experimental on older minespoils in Illinois, Missouri, Kansas, and Oklahoma. Species *bignonioides* performs well in Alabama.				
Flowering dogwood *(Cornus florida)*	N	T	4.5	H,E
Comments: Fruit and browse for wildlife. Survival of planted seedlings often quite low, and growth slow. Volunteer seedlings sometimes found in established woody vegetation. Native to most of eastern coal regions.				
Hackberry *(Celtis occidentalis)*	N	M to T	5.0	H,F,E
Comments: Volunteer seedlings often numerous on older sites where forest vegetation is becoming reestablished. Some artificial plantings in Illinois, Missouri, and Kansas. Native in most of Interior Region.				
Hickories *(Carya* spp.)	N	I	5.0	H,F
Comments: Species used in recent planting in Illinois include *C. ovata, C. tomentosa, C. cordiformis, C. glabra,* and *C. laciniosa*. No other plantings for long-term evaluation. Grow best on neutral soils. Native in Interior and part of Lignite Regions.				
Red mulberry *(Morus rubra)*	N	M	5.0	H
Comments: A common volunteer on older mined areas in Interior Region where forest vegetation is reestablishing. Recommended for wildlife habitat plantings in southwestern part of Interior and western part of Lignite Regions, though there are few documented plantings on mined land.				
Chestnut oak *(Quercus prinus)*	N	M	4.5	F,H
Comments: Similar site requirements as white oak. Central Appalachian.				
Pin oak *(Quercus palustris)*	N	I	4.0	H,F,E
Comments: Volunteers on older forested sites. Potential value for planting mined land probably greater than past use indicates. Adapted to wet, poorly drained shallow soils. Native in most of Interior Coal Region. Successfully planted in eastern Kentucky at lower elevations.				
Shingle oak *(Quercus imbricaria)*	N	I	4.0	H
Comments: Often volunteers on older mined sites where forest vegetation is reestablishing. Native in eastern part of Interior Region. Some successful plantings in Central Appalachian Region, but no long-term evaluation of artificial plantings.				
White oak *(Quercus alba)*	N	M	5.0	F,H
Comments: Not planted widely on mined lands. Survival of most plantings was low. In some plantings survival and growth was better where interplanted with black locust. Potentially valuable timber species. Native in most of Eastern Coal Regions.				
Other oaks *(Quercus* spp.)	N	–	–	—
Comments: Other species of oaks probably have the same potential for success on minesoils as those that have been tested and used. Some of these are black oak, blackjack oak, chestnut oak, post oak, shumard oak, and southern red oak. Selection should be based on proposed land use and adaptation of the species to site and region.				

*I = Introduced; N = Native.
†T = Shade tolerant; I = Shade intolerant; M = Intermediate tolerance.
‡F = Forest products; H = Habitat for wildlife; E = Esthetics and screening; C = Christmas trees.

Table 20. Tree species of lesser importance or use.

Common and Scientific Name	Origin*	Tolerance†	Lower pH Limit	Major Uses‡
		HARDWOODS, continued		
Russian olive *(Elaeagnus angustifolia)*	I	M	5.5	H,E
Comments: Small tree or large shrub. Much used for shelterbelts in Midwest. Adapted to most of Interior and western part of Lignite Region.				
Royal paulownia *(Paulownia tomentosa)*	I	M	4.5	F,E
Comments: A rapid-growing tree with high market value for export to Japan. Has escaped from cultivation. Volunteers on some spoils, but may be difficult to establish artificially. Central and Southern Appalachian Regions.				
Pecan *(Carya illinoensis)*	N	I	5.0	H,F
Comments: Older plantings in Missouri, Kansas, and Oklahoma not successful due to repeated browsing by deer. Native in southern part of Interior and most of Lignite Regions.				
Black willow *(Salix nigra)*	N	I	4.5	H,E
Comments: Most suited for low wet sites and stream margins. Can withstand flooding and silting. Native to all Eastern Coal Regions.				

*I = Introduced; N = Native.
†T = Shade tolerant; I = Shade intolerant; M = Intermediate tolerance.
‡F = Forest products; H = Habitat for wildlife; E = Esthetics and screening; C = Christmas trees.

Suggested Species Mixtures

Revegetation strategies for most land uses require mixtures of plant species and plant types. For example, at least two herbaceous species normally are used in the establishment of pasture. Revegetation for forestry and wildlife habitat generally includes several woody species and one to several herbaceous species. In addition to being functional, mixtures of plant types improve esthetic or visual interest and diversity. Only in some agricultural uses, such as grain and row crops, is one species involved.

For most land uses, introduced species or combinations of introduced and native species are planted. Usually it is impractical to immediately reestablish stands of vegetation that are entirely "native," especially where herbaceous cover is needed quickly for erosion control. For example, in vegetating for forestry and wildlife habitat, many of the commonly used tree species are native, but most of the herbaceous species and frequently used shrubs are introduced. With few exceptions, the establishment of native herbs and shrubs will depend largely on natural seeding (invasion) from surrounding native stands. The development of predominantly native vegetation may require several to many years depending largely on the combination, density, and persistence of the introduced species used for ground cover.

Species mixtures for several land uses are discussed in this chapter. It is not feasible to list all of the species combinations that could be used. However, the several examples given may help illustrate the rationale for mixing species for the various land uses. Because the Interior Coal and Southern Lignite Regions include a wide range of climate and natural vegetational types, recommended species and mixtures may differ between and within regions.

Herbaceous Vegetation

For nearly all land uses, the quick, initial establishment of herbaceous vegetation is necessary for control of water and wind erosion. Vegetation for watershed protection is especially important in mountainous and sloping areas where erosion caused by runoff is potentially greatest. In many cases, mixtures recommended for erosion control also are suitable for forage, wildlife habitat, and ground cover in tree plantations.

Erosion Control and Agriculture

Examples of seeding mixtures suggested primarily for erosion control are shown in Tables 21 to 23. Mixtures for spring, summer, and fall seeding times are suggested. These mixtures include an annual or short-lived perennial species that provides quick but temporary cover. One of these should be chosen and added to a mixture containing at least one perennial grass and one perennial legume. Ideally, as the perennial species succeed they will replace the temporary species. Where there is a choice, the grass and legume species best adapted to the minesoil properties and climate should be selected. It is important to not exceed seeding rate recommendations for the quick-cover temporary species, because higher rates of these species could produce dense stands that prevent or retard the establishment of the perennial species.

Table 21. Suggested herbaceous mixtures for erosion control and alternatives for forage in the Northern Appalachian Region (Seeding rate: pounds per acre PLS).

Seeding Time	*Temporary (quick-cover) Species* (Use One with Permanent Mix)*		*Permanent (long-lived) Species*			
			Erosion Control		*Forage or Wildlife*	
Early to midspring	Annual ryegrass	5	Ky-31 tall fescue†	15	Orchard grass or Timothy	8 6
	Perennial ryegrass	10	Birdsfoot trefoil or	6	Red clover and Ladino clover	5 2
	Oats	48	Crownvetch or	10	or Kura clover	 8
	Weeping lovegrass	2½	Flatpea or Sericea lespedeza	20 15	or Alfalfa	 10
Midspring to midsummer	Foxtail millet	12	KY-31 tall fescue	15	Same as above but spring or fall seeding preferred	
	Japanese millet	15				
	Weeping lovegrass	2½	Birdsfoot trefoil or Crownvetch or Flatpea	8 10 20		
Midsummer to early fall	Rye	40	KY-31 tall fescue	20	Orchardgrass or Timothy	10 8
	Winter wheat	40	Redtop	2	Red clover and Ladino clover	6 3
	Annual ryegrass	5	Birdsfoot trefoil or Crownvetch	8 20	or Kura clover or Alfalfa	 8 12

* Use one of the temporary species at rates shown; if more than one species is used, reduce seeding rate of each in proportion to number used, e.g., for two species use one-half seeding rate of each.

† All species listed in this column (except perhaps flatpea) have value for forage but the quality may be somewhat lower than those species listed under forage and wildlife.

Some of the mixtures also are suited for forage production; however, a few of the species that are well suited for erosion control and site stabilization are not the most suitable for other land uses. For example, sericea lespedeza and flatpea are excellent for long-term erosion control, but their value for forage is lower than that of other legume species, such as alfalfa. Thus, consideration should be given to selecting species for their suitability for the approved land use, as well as for controlling erosion. Some alternate mixtures for forage use also are given in Tables 21 to 23.

Forestry

The seeding of herbaceous species before or concurrent with the planting of trees nearly always is needed to prevent erosion. However, the herbaceous cover also may slow or prevent the establishment of the trees. Where herbaceous cover is established first, it may be necessary to kill or suppress it with herbicides or cultivation before planting trees. In the more humid regions of the East, especially in Appalachia, it sometimes is possible to establish trees by planting them concurrent with the seeding of herbaceous species. The success or failure of trees so planted appears to be partly, if not largely, related to the amount and distribution of precipitation during the growing season.

Table 22. Suggested herbaceous mixtures for erosion control and alternatives for forage and wildlife for the Southern Appalachian Region (Seeding rate: pounds per acre PLS).

Seeding Time	Temporary (quick-cover) Species* (Use One with Permanent Mix)		Permanent (long-lived) Species			
			Erosion Control		Forage or Wildlife	
Early to midspring	Perennial ryegrass	10	Ky-31 tall fescue	15	Orchard grass or Switchgrass	10 / 12
	Oats	48	Korean and/or Kobe lespedeza†	10	Korean lespedeza	10
	Weeping lovegrass	2½				
	Annual ryegrass	5	Sericea lespedeza or Crownvetch	15 / 10	Ladino clover	3
Midspring to midsummer	Weeping lovegrass	2½	KY-31 tall fescue	20	Same as above or Bermudagrass could be seeded or sprigged in place of grasses. above. Little or no seed of quick cover species needed	
	Pearl millet	10	Korean and/or Kobe lespedeza†	10		
	Sorghums	20				
	Browntop millet	15	Sericea lespedeza	15		
	Foxtail millet	12				
Midsummer to early fall	Rye	50	KY-31 tall fescue	20	Orchardgrass	12
	Winter wheat	50			Ladino clover	4
	Annual ryegrass	5	Sericea lespedeza‡ or Crownvetch	20 / 12	Crimson clover§	6
	Perennial ryegrass	12				
	Crimson clover	12				

* Use only one of the temporary species at rates shown; if more than one is used, reduce seeding rate of each species in proportion to number used, e.g., for two species use one-half seeding rate of each.

† These annual lespedezas usually reseed each year and may become a permanent component of the vegetative cover.

‡ One-half or more of sericea lespedeza seed should be unhulled and unscarified to reduce amount of fall germination and ensure sufficient seed for germination the next spring.

§ Reseeding varieties may become a continuing component of cover. Include a permanent component only with temporary grass species.

Results of limited research also suggest that some herbaceous species are more compatible than others with contemporaneously planted woody species. In eastern Kentucky, for example, where Ky-31 tall fescue and sericea lespedeza were planted with trees, the growth of trees was suppressed in cover that was predominantly fescue but was favored in cover that was predominantly lespedeza, a legume. Thus, legumes seem to be a better choice than grasses for use with trees, unless the legume plants grow so large and dense that the tree seedlings are smothered before they can grow above the legume plants. Low-growing legume species and varieties, therefore, are preferred for combination plantings with trees. Tall or aggressive legumes, such as common sericea lespedeza, crownvetch, and flatpea, are least recommended for combination plantings with trees. Where adapted, other low-growing legumes, such as Korean lespedeza and Appalow sericea lespedeza, could be substituted for the crownvetch, flatpea, or common sericea lespedeza. Herbaceous mixtures for use with trees could be similar to those suggested for forage and wildlife in Tables 21 to 23.

Temporary Cover. Annual species can be used effectively in tree planting programs where a temporary cover is established one year and trees are planted the following spring. Where early-spring seeding is required, a heavy seeding of oats, wheat, rye, or annual ryegrass can be used. Where adapted, an annual legume such as Korean or Kobe lespedeza can be included. For late-spring and early-summer seedings, summer annuals, such as sorghum, Japanese millet, or pearl millet, are useful. For late-summer and fall seeding, winter annuals, such as wheat, rye, annual ryegrass, hairy vetch, or crimson clover, can be used. However, winter annuals may pose a problem for tree planting the following spring in that they will be established and actively growing when the newly planted tree seedlings are trying to become established. Herbicides or tillage in spots or strips may be required to suppress the fall-planted cover before the tree seedlings are planted. But, where spring precipitation is adequate to support both the cover and woody species, these annuals may not present a problem because they will be mature before summer and, therefore, will not compete with trees for moisture during the summer when moisture is most likely to be limited.

Seeding and Planting in Alternate Strips. Trees and herbaceous cover can be established together by seeding mixtures of herbaceous species in strips or bands that alternate with strips planted only to trees. The width of the seeded strips can vary to facilitate the desired tree spacing. Where trees are planted at an 8- by 8-foot spacing, for example, 5-foot-wide strips of a grass-legume seeding could alternate with 3-foot-wide strips that are not seeded. The tree seedlings are planted 8 feet apart in the middle of the unseeded strips. The herbaceous cover in alternating strips will provide adequate ground cover for erosion control yet produce minimum competition to the tree seedlings during the initial growth period.

Alternate strip planting will work best on areas that can be traversed with farm equipment, because a grain or grass seeding drill and a drop-type fertilizer spreader would be most useful for establishing strips that are uniform in width. On sloping land the strips should run on contour.

Wildlife Habitat

Grass-legume mixtures suggested for wildlife habitat are listed in Tables 21 to 23. These are similar to mixtures suggested for controlling erosion except that plant species considered more desirable for wildlife replace less suitable ones. For example, grasses such as orchardgrass, timothy, deertongue, reed canarygrass, switchgrass, Dallisgrass, and Kentucky and Canada bluegrasses are recommended in place of Ky-31 tall fescue. Similarly, limited use should be made of legumes such as common sericea lespedeza, crownvetch, and flatpea that will dominate the vegetational cover and limit the diversity of food and cover. Also, the dense persistent cover of these legumes may retard or prevent the invasion and establishment of native plant species that contribute to habitat diversity. Herbaceous legumes that are desirable food plants but less aggressive and persistent than the three legumes mentioned should be used. These include red clover, white clover, alsike clover, birdsfoot trefoil, partridge pea, arrowleaf and crimson clovers, or the annual lespedeza species.

Mixtures of native warm-season grasses—switchgrass, Indiangrass, big bluestem, and little bluestem—are useful for providing nesting cover for certain game birds and cottontail rabbit. Where adapted, mixtures containing Japanese millet, redtop, reed canarygrass, or alsike clover are suggested for wet or poorly drained areas and pond borders. Mixtures seeded in food patches for song and game birds could include wheat, common sunflower, foxtail millet, browntop millet, soybean, cowpea, or buckwheat.

Table 23. Suggested herbaceous mixtures for the Interior Coal and Southern Lignite Region (Seeding rates: pounds per acre PLS).

Region	Seeding Time	Temporary (quick-cover) Species* (Use One with Permanent Mix)		Permanent (long-lived) Species	
Interior Region, northern half	Early to midspring	Oats	40	Smooth bromegrass	15
				or	
		Annual ryegrass	5	Tall fescue	15
				or	
		Perennial ryegrass	10	Reed canarygrass	8
				or	
				Orchardgrass	6
				Alfalfa	10
				or	
				Birdsfoot trefoil	8
				or	
				Crownvetch	10
Interior Region, southern half	Early to mid spring	Perennial ryegrass	10	Tall fescue	15
		Oats	48	Korean and/or Kobe lespedeza†	10
		Weeping lovegrass	2		
				Sericea lespedeza	15
				or	
				Crownvetch	10
	Midsummer to early fall	Rye	40	Tall fescue	20
		Winter wheat	40	Sericea lespedeza‡	15
				or	
		Annual ryegrass	5	Crownvetch	10
		Perennial ryegrass	10		
		Crimson clover	12		
				Native species mix	
Western Interior Coal Province	Spring	Oats (A temporary cover species may provide excessive competition with perennials. Mulch only may be more suitable.)	32	Switchgrass	2
				Big bluestem	3
				Little bluestem	2
				Indiangrass	4
				Sideoats grama	3
				Illinois bundleflower	1
				Partridge pea	2
Southern Lignite Region, eastern two-thirds	Spring to midsummer	Pearl millet	12	Bahiagrass	25
		Sorghum	20	Sericea lespedeza	15
		Browntop millet	20	Kobe lespedeza	10

* Use only one of the temporary species at rates shown; if more than one is used, reduce seeding rate of each species in proportion to number used, e.g., for two species use one-half seeding rate of each.

† These annual lespedezas usually reseed each year and may become a permanent component of the vegetative cover.

‡ One-half or more of sericea lespedeza seed should be unhulled and unscarified to reduce amount of fall germination and ensure sufficient seed for germination the next spring.

Woody Vegetation

Timber Management

Trees can be planted either in pure stands of one species or in mixtures of two or more species. In general, stands of one species are easier to plant, manage, and harvest; but they are more susceptible than mixed planting to insect and disease epidemics and lack diversity for visual quality and wildlife habitat. Mixed plantings improve the possibilities for natural diversity and regeneration and usually occupy the site more fully than pure plantings. The following are general guides for pure and mixed plantings of trees.

1. Pure plantings of pine usually are favored over mixtures of pine. Where two or more pine species are desired, plant a block or group of several rows of one species that alternate with blocks of the other species. A block or group should consist of at least five rows. An exception may be a mixture of species with similar growth rates, such as pitch and shortleaf pines.
2. Mixing hardwoods with intolerant pine species is not recommended. Hardwoods usually shade out the pine. Mixing groups or blocks of pine and hardwoods are acceptable, especially where diversity in cover types is desired for esthetic purposes and wildlife habitat. Intimate mixing of tolerant conifers, such as spruce and white pine, with tolerant hardwoods and slow-growing hardwoods is acceptable.
3. Hardwood species, such as hybrid poplar and European alder, that will produce a quick crop (pulpwood) and be harvested can be planted in alternate rows with conifers (except larch with hybrid poplar, Northern Ap-

palachian Region). A coniferous stand will follow after the hardwoods are harvested.

4. For a few hardwoods—cottonwood, sycamore, and hybrid poplar—planting in pure stands or block mixtures is preferred, especially where planned use is for pulpwood. Most other hardwoods also can be planted in pure stands or blocks, but mixtures generally are recommended. The planned utilization of the trees will determine the feasibility of planting pure or mixed stands.
5. Black locust, European alder, or autumn olive may be beneficial as "nurse" species in hardwood mixtures. Red oak, yellow-poplar, hybrid poplar, sweetgum, green and white ash, and sugar maple are some of the species suggested for planting with a nurse crop. Growth of pine also may be enhanced where interplanted with European alder. The nurse species generally should make up no more than one-fourth to one-third of a hardwood mix.
6. The presence of nitrogen-fixing trees like black locust and European alder will encourage the natural establishment of indigenous (native) forest species. Thus, planting mixtures of numerous tree species may, in the long run, offer little advantage over simple mixes that include these nurse species.

The following are examples of hardwood mixtures planted for timber production:

Northern Appalachian Region

Species	*Composition* (percent)
Example 1	
Northern red oak	25
Green or white ash	25
European white birch	25
European black alder	20
Autumn olive or Indigobush	5
Example 2	
Northern red oak	20
White or green ash	20
Sycamore	10
Yellow-poplar	20
Red maple	10
Black locust	20

Southern Appalachian Region

Species	*Composition* (percent)
Northern red oak	20
White or green ash	20
Sycamore	10
Yellow-poplar	20
Red maple	10
Black locust	20

Central Hardwoods Area of the Eastern Interior Coal Province

Species	*Composition* (percent)
Northern red oak	20
White or green ash	20
Sycamore	10
Yellow-poplar	20
Red maple	10
Black locust	20

Oak-Hickory Type in the Western Interior Coal Province

Species	*Composition* (percent)
Green ash	20
Bur oak	25
Sycamore	20
Black cherry	10
Black locust	25

Obviously, many combinations of species besides those suggested are possible, and the choice of species should be influenced by such factors as the natural range of the species, minesoil characteristics, availability of planting stock, market preferences, potential commercial value and the character of the surrounding landscape and vegetation. For a given locality, consult appropriate natural resource agencies and State revegetation and forestry guides for additional advice on forestry procedures and species selection.

Wildlife Habitat

A variety of shrubs and some trees are select choices for plantings for wildlife cover and food. Usually, small blocks or strips each containing a single species are recommended over random mixing of species. However, several blocks or strips each containing a different species can be planted on a given area. For maximum diversity, select species that are least abundant in the surrounding unmined vegetation. For example, if predominantly hardwood forest, plant patches of pine and fruit-producing trees and shrubs, such as crabapple, autumn olive, amur honeysuckle, shrub lespedeza, indigobush, and amur privet, interspersed with patches or strips of herbaceous vegetation and food patches. If predominantly a pine forest area, plant hardwoods like sawtooth oak, white ash, crab apple, and red maple and several shrub species. If the surrounding environs are mainly crop and pasture land, plant patches or strips of hardwoods, pine, shrubs, and herbaceous cover interspersed with one another.

REVEGETATING COAL SURFACE-MINED LANDS IN THE WESTERN COAL REGION

The purpose of this chapter is to (1) briefly describe the coal region in the western United States, (2) list and describe plant species suitable for revegetating surface-mined lands and criteria for selecting those species, and (3) provide some guidelines for selecting species and species mixtures for different land uses.

The Western Coal Region lies primarily west of the 100th meridian. This region contains large fields of lignite, subbituminous, and bituminous coals (Figure 35). It spans 15 degrees of latitude and 24 degrees of longitude and encompasses great variation in climate, topography, and geology. Because much of the region is mountainous, local climatic variation due to differences in elevation can be greater than variation due to latitudinal differences. As a result, the native vegetation is extremely heterogeneous over the region as a whole and within localized areas. In some areas, it is possible to go in a short distance from desert shrub vegetation through conifer forest to alpine tundra.

Geology and Physiography

Because of its size and geomorphic complexity, the geology of the Western Coal Region defies concise description. At least 15 major geomorphic provinces are included in the region and elevations range from below sea level to above 14,000 feet.

The region is extensive and diffuse, with coal being mined in portions of the Great Plains, Rocky Mountains, Great Basin, Wyoming Basin, Intermountain Basin, Colorado Plateau, and North Pacific Valley region of western Washington.

The Western Great Plains is predominantly a high, level plateau which rises gradually in elevation as one moves westward before encountering the abrupt Front Range of the Rocky Mountains. The plateau is dissected occasionally by badlands or breaks, particularly along the Missouri River drainage. The plateau is broken occasionally by small island-like mountains, of which the Black Hills of the Dakotas are the largest and best known. The parent materials of the Great Plains are primarily of Mesozoic and Cenozoic age, though they may be covered with Tertiary material where glaciation has not removed it.

The Rocky Mountains is a collective term for numerous mountain ranges extending south-southeast from Canada

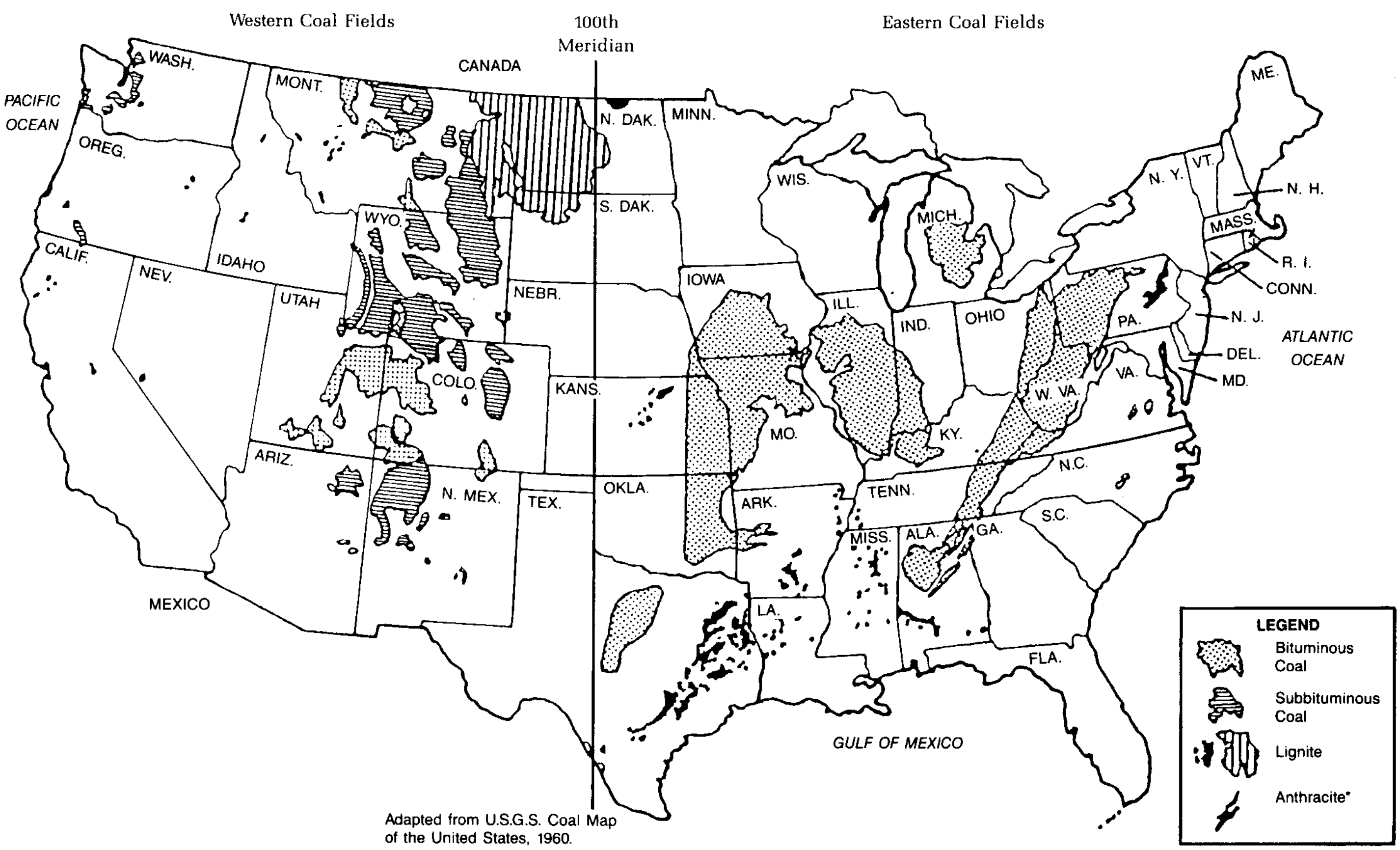


Figure 35. Coal fields of the continental United States.

to Mexico. The mountains are primarily the result of late Mesozoic displacement which has exposed a core of Precambrian rock as the result of block and thrust faulting. However, there are significant igneous intrusions and extrusions, primarily in the north.

Much of the Western Coal Region is best described as intermontane basin. The Wyoming Basin is a high basin formed from erosional debris of the adjacent mountains, which is primarily of the Tertiary period. In general, the Wyoming Basin is divided by remnant mountain ranges into several distinct basins.

The Great Basin is a region of scattered, small mountain ranges with wide areas of erosional flats. The geologic nature of the materials is diverse, as the mountains result from local block-faulting of rocks of all geologic ages.

The Colorado Plateau is an extensive area of high elevation, gently dipping sedimentary rock in southern Utah, western Colorado, northern Arizona and northern New Mexico. The plateau actually is composed of numerous smaller plateaus, divided by deeply incised river canyons. Variability in the hardness of the sediments has led to conspicuous formation of escarpments and benches. The rocks range in age from Precambrian to recent.

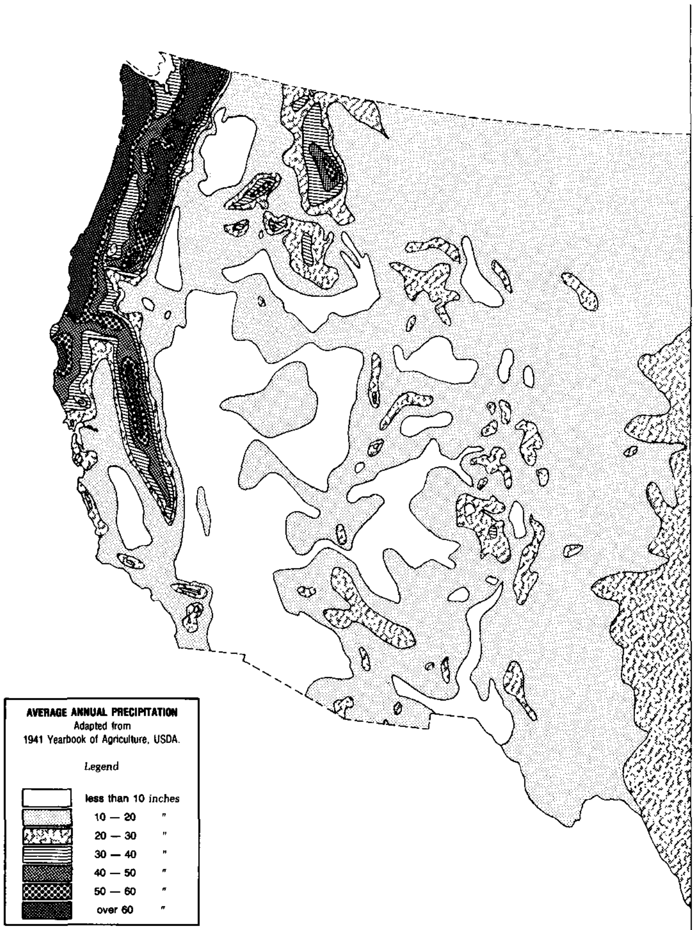


Figure 36. Precipitation zones of the western United States.

Subbituminous coal is found in western Washington where the Puget Trough, a narrow lowland, borders the Cascade Mountains. The associated geology is probably of the Tertiary period.

Climate

Precipitation

Much of the Western Coal Region is arid to semi-arid. Only the area west of the Cascade Mountains in the Pacific Northwest and high-elevation sites in the mountains receive abundant precipitation. Mean annual precipitation in the portions of the region where coal is mined ranges from 8 to 50 inches, though sites with more than 30 inches are few (Figure 36). The regional trend, disregarding local topographic effects and the North Pacific Valley area, is an increase in mean annual precipitation from about 8 inches on the western edge of the region to about 16 inches at the eastern edge. In the mountainous portions, mean annual precipitation is primarily related to elevation rather than to position in the east/west precipitation gradient. For example, in Utah, mean annual precipitation ranges from 8 inches in the valley bases to more than 40 inches in the high mountains. Thus, the effect of topography generally is much more significant than the effect of geographic location. In general, however, the vast majority of coal fields lies in the foothills or intermontane basins of the region, and does not benefit from the additional moisture available at higher elevations. In fact, most of the identified coal fields in this region receive between 10 and 16 inches of precipitation (Packer et al. 1982). Even this narrow range, however, represents a 60 percent increase in precipitation from the drier sites to the wetter, which translates into a significant difference in revegetation potential. By contrast, the coal mining area in western Washington receives about 50 inches of precipitation per year.

Mean annual precipitation can be a misleading indicator of plant growth potential because the response of the vegetation depends strongly on the seasons during which the precipitation is received. Precipitation received during the growing season usually contributes more to plant growth than precipitation received during the winter. Additionally, growing-season precipitation tends to favor grasses and other shallow-rooted forbs, whereas winter precipitation tends to favor shrubs and other deep-rooted species.

The major portion of the Western Coal Region can be divided into several areas on the basis of seasonality of precipitation (Figure 37). North and South Dakota, eastern Montana, eastern Wyoming, and eastern Colorado lie in an area where maximum precipitation occurs in late spring or early summer. Accordingly, the vegetation throughout this region is dominated by grass species, which make the best use of this growing-season precipitation.

By contrast, western Wyoming, western Colorado, Utah, and western Arizona receive precipitation that is more evenly distributed throughout the year. In response, the vegetation in these areas is dominated primarily by shrubs and, where sufficient moisture is received, by trees. In New Mexico and eastern Arizona, the months of greatest precipitation are July, August, and September. This precipitation pattern favors shrubs or grasses that show a prominent fall green-up.

In the coal mining area of western Washington, half of the precipitation falls in winter and less than 5 percent in July and August. Trees, notably Douglas-fir, are the predominant natural vegetation.

Year-to-year variation in precipitation also affects the amount of moisture that vegetation can use effectively. For example, an area may have a long-term mean annual precipitation of 12 inches. Typically, precipitation is less than average (7 to 9 inches, for example) the majority of years, and only infrequently is it far above average (20 inches, for example). But the vegetation is predominantly of species and types adapted to survive with no more than about 8 inches of precipitation. With 20 inches of precipitation, much of the extra 12 inches may run off, depending on the intensity of the storm and soil properties, and possibly cause severe erosion. Certainly, the vegetation will show increased production in wet years, but the increase may not be proportional to the increase in precipitation. More importantly, species that require 12 inches of precipitation will fail to establish, even though the mean annual precipitation is 12 inches.

Throughout the Western Coal Region there is a trend for the year-to-year variation in precipitation to become increasingly greater from north to south. Thus, mean annual precipitation is more predictable in the north than in the south, and consequently more reliable for predicting revegetation potential in the north. In Arizona and New Mexico especially, revegetation strategies should be designed for the "typical" or low precipitation years rather than for the average year.

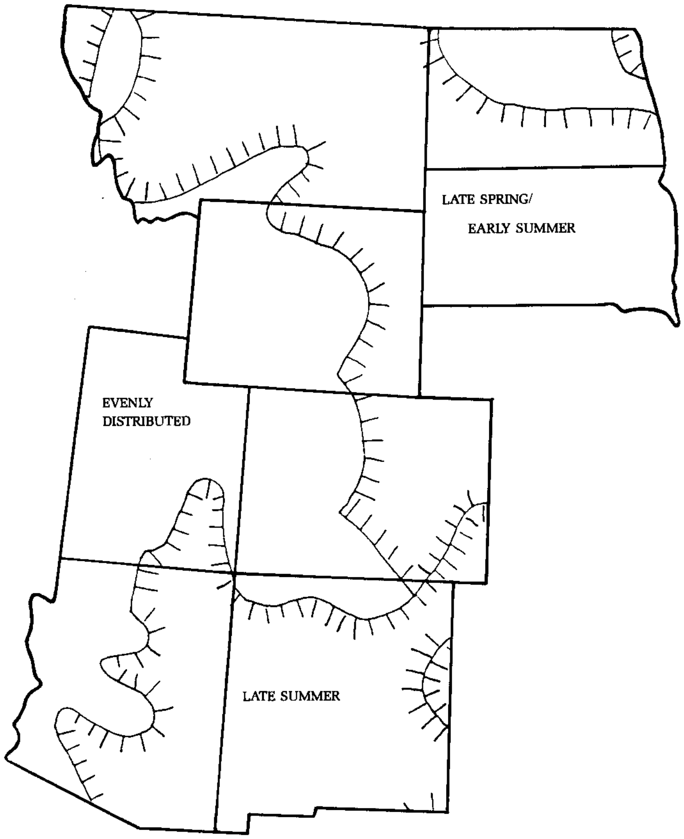


Figure 37. Seasonal precipitation differs among regions of the western United States.

Available Moisture

Precipitation is one of the two primary components of the moisture budget of a given site; evaporative demand is the other. Two sites may receive identical precipitation but have different moisture relations where one site is more exposed to insolation or wind than another.

Evaporative demand is strongly determined by temperature; there is generally a strong increase in evaporative demand from north to south latitudes, and from northeast- to southwest-facing slopes, for example. Crop scientists have calculated the balance between precipitation and evaporative demand (Thornthwaite 1948, Wilsie 1962). Figure 38 shows relative moisture availability for the United States. The availability of natural water is deficient for most of the Western Coal Region.

As would be expected in a mountainous region, moisture availability is controlled largely by elevation, with high-elevation sites generally more moist than low-elevation sites. Irrespective of topography, however, there is a general trend of increasing available moisture from west to east, with least in the Great Basin in Utah and most in North and South Dakota.

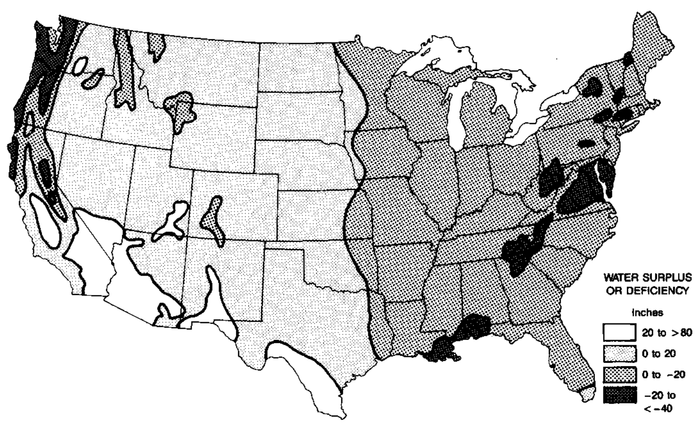


Figure 38. Areas of natural water surplus and deficiency (computed by subtracting potential evapotranspiration from average precipitation). From U. S. Water Resources Council 1968.

Temperature

The growing season for plants is commonly considered to be the time between the last frost in the spring and the first frost in the fall, referred to as the frost-free season. Because the Western Coal Region extends across 15 degrees of latitude, there is a gradient from relatively short growing seasons in the north to long growing seasons in the south (Figure 39). The normal frost-free season in North Dakota and eastern Montana is about 120 days, and in Arizona about 200 days. These values are for low-elevation sites. In the mountainous areas, the frost-free season is more strongly determined by elevation than by latitude. Frost-free seasons of 90 days are common throughout the Rocky Mountain area, but at the higher elevations in Wyoming and Colorado, the frost-free season may be as short as 30 days.

As noted previously, most of the known coal fields are not in the high mountains and so have moderate frost-free seasons. The range for the known coal fields is from 60 days in the mountains of Colorado to 160 days in Arizona and New Mexico (Packer et al. 1982) and 170 to 180 days in western Washington.

In the arid west, the growing season as determined by the frost-free season may not be the actual period of plant growth in a given area. Throughout much of the region, and particularly in the south, summer drought may be severe enough to prevent plant growth. Thus, there is a growing season in the spring when moisture is available, a period of aestivation in the summer when plants are dormant, and a second growing season in the fall when moisture again becomes available. Consequently, the potential period for establishing vegetation in these areas may be less than indicated by the frost-free season.

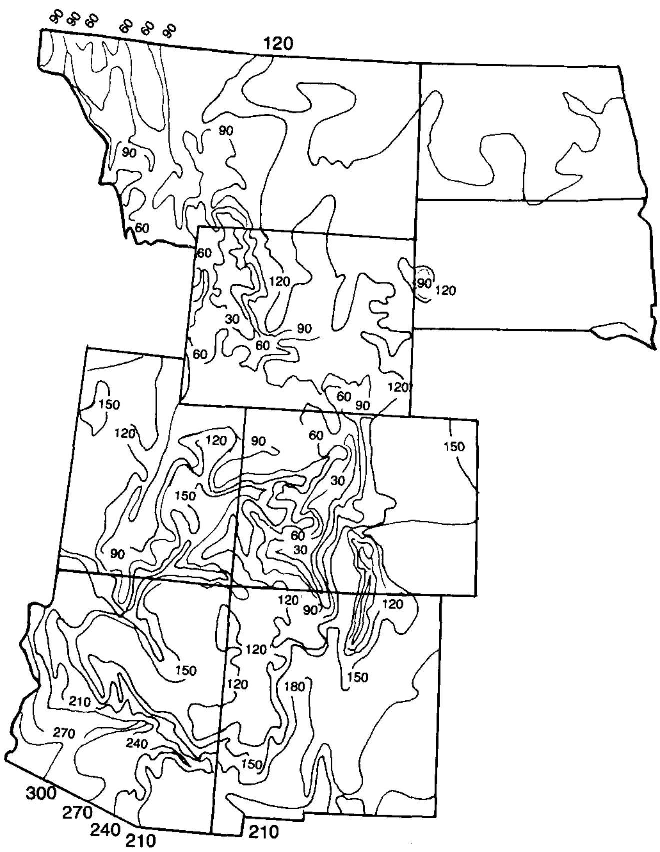


Figure 39. Frost-free periods (length of growing season) in days for the Western Coal Region. The frost-free period in western Washington is 170-180 days. From U. S. Department of Commerce 1968.

Native Vegetation and Plant Communities

The pronounced climatic and geologic variability of the Western Coal Region gives rise to extremely diverse vegetation. Plant communities may be dominated by grasses, shrubs, or trees, and the species composition of the various communities may vary greatly.

Some of the vegetation diversity is attributable to regional trends in climate. In many areas, the influence of mountains on the local climate is responsible for increasing the diversity of vegetation. The nature of the exposed geologic strata and the influence of these strata on the properties of the soil derived from them are responsible for additional vegetation diversity.

For the purposes of this handbook, a classification of the vegetation of this region follows that proposed by Kuchler (1964), which divides the vegetation of the United States into many vegetation types. Sixteen of these vegetation types, exclusive of western Washington, were chosen for their regional importance and proximity to known coal fields and are described here.

Four qualitatively different climatic zones within the Western Coal Region were outlined previously. Three of these are shown in Figure 37. They are: (1) a zone with maximum late-spring and early-summer precipitation, coincident with the Great Plains; (2) a zone of fairly uniformly distributed annual precipitation, generally coincident with the Great Basin; (3) a zone with a late-summer precipitation maximum in the southeastern part of the region; and (4) winter precipitation with dry July and August coincident with the North Pacific Valleys in western Washington. The presentation of the vegetation types follows this outline, beginning with the Great Plains.

Great Plains Vegetation Types (Maximum Precipitation in Early Summer)

There are six vegetation types characteristic of the Great Plains included in this report. In general, these types can be stratified by moisture, temperature, and topography. Four are grassland types which occur on soils typical of a prairie region. The other two are savanna or forest types which occur on rocky or upland sites in eastern Montana and the Black Hills.

Wheatgrass-Bluestem-Needlegrass

The wheatgrass-bluestem-needlegrass vegetation type is a minor component in the Western Coal Region, occurring primarily in central North and South Dakota. This type represents the western boundary of the tallgrass prairie and occupies the most mesic sites of the prairie types considered. It is in a 14- to 18-inch precipitation zone, with a frost-free period of 110 to 160 days.

The structural diversity of the type is low, with a strong dominance by grasses. Dominant species are big bluestem, porcupine grass, western wheatgrass, little bluestem, narrow-leaved sedge, and other sedges. Additional commonly occurring grass species include blue grama, needle-and-thread, prairie junegrass, side-oats grama, and prairie sandreed. Important shrubs and forbs include fringed sagebrush, silver sage, blazing star, and Arkansas rose (Hanson and Whitman 1938, Kuchler 1964).

Wheatgrass-Needlegrass

The wheatgrass-needlegrass vegetation type occupies cool, mesic sites in the northern Great Plains, and covers most of western North and South Dakota, as well as the northeast corner of Wyoming. This area receives 14 to 16 inches of precipitation annually, with a frost-free period of 110 to 150 days.

This vegetation type has low structural diversity and is dominated almost totally by grasses. The dominant species are western wheatgrass, blue grama, needle-and-thread, green needlegrass, and prairie junegrass. Other graminoids (grass and grass-like species) include thread-leaved sedge, thick-stem wheatgrass, and little bluestem. Important forbs and shrubs include fringed sagebrush, prickly pear, scarlet globemallow, showy sunflower, and several species of goldenrod and pussytoes (Hanson and Whitman 1938, Kuchler 1964, Quinnild and Cosby 1958).

Grama-Needlegrass-Wheatgrass

Grama-needlegrass-wheatgrass is the characteristic vegetation type of the Great Plains of Montana. It also occurs extensively in eastern Wyoming and extends into northern Colorado. This vegetation type occupies the cool dry extreme of the Great Plains, occurring in a precipitation zone of approximately 10 to 16 inches, with a frost-free period of about 100 to 140 days.

The structural diversity of this type is low, as the appearance of the community is dominated overwhelmingly by grasses. The few shrubs present generally are low-growing forms. Forbs are relatively unimportant. The dominant species in the community are western wheatgrass, blue grama, and needle-and-thread. Other graminoids are often important, especially thread-leaved sedge, prairie junegrass, and bluebunch wheatgrass. In the southern end of the type, side-oats grama also may be important. Shrubs and forbs are relatively unimportant in terms of biomass, but add some diversity to the type. Fringed sagebrush is commonly encountered, as are the forbs Drummond's milk-vetch, little sunflower, and hairy goldaster (Costello 1944, Hanson 1955, Kuchler 1964, Moir 1969, Wright and Wright 1948).

Grama-Buffalo Grass

The grama-buffalograss vegetation type is characteristic of the Great Plains of eastern Colorado, eastern New Mexico, and southeastern Wyoming. It occupies warm dry sites in the Great Plains, with a precipitation range from 12 to 16 inches and a frost-free period from 120 to 160 days.

As with all of the Great Plains vegetation types, structural diversity is low. The vegetation is dominated overwhelmingly by grasses, with generally only minor amounts of shrubs or forbs. Blue grama and buffalograss are the dominant species, and together constitute the vast bulk of the vegetation. Other important graminoids include western wheatgrass, galleta, thread-leaved sedge, prairie junegrass, and needle-and-thread. Fringed sagebrush, snakeweed, and prickly pear are the most common shrubs, but collectively contribute little to the biomass of the community. Forbs are relatively more important than shrubs, but still contribute little to community composition. The most important species is gumweed, which may be accompanied by sunflowers or woolly indianwheat (Beetle 1952, Branson et al. 1965, Costello 1944, Kuchler 1964).

Black Hills Pine

As defined here, the Black Hills pine forest includes the mesic nonsavanna pine forest of the Black Hills and mesic pine forests in southeastern Montana. The dry pine savannas of the Black Hills are included in the eastern ponderosa pine vegetation type.

The Black Hills pine vegetation type occupies mesic or moist sites on mountain slopes or foothills in the northern Great Plains. Mean annual precipitation on these sites ranges from 14 to 22 inches. Stands often are situated on cooler aspects or protected slopes which help maintain site moisture. The frost-free period ranges from 100 to 140 days.

Structural diversity is fairly high, with a moderate to dense overstory of ponderosa pine, commonly both high and low shrubs, and abundant grasses and forbs. The compositional diversity also is high. Thilenius (1972) defined 10 plant communities for the Black Hills; Pfister et al. (1977) added 2 for eastern Montana. In addition to ponderosa pine, the overstory may include quaking aspen, green ash, bur oak, and paper birch. Common understory shrubs include common juniper, Canada buffaloberry, chokecherry, Saskatoon serviceberry, western snowberry, creeping holly grape, shrubby cinquefoil, and fringed sagebrush. Grasses and forbs are numerous; important species include rough-leaved ricegrass, false melic, rough hairgrass, timber oatgrass, various species of sedge, heart-leaf arnica, wartberry fairybell, northern bedstraw, yarrow, strawberry, various species of violet, cream-flowered peavine, American vetch, and prairie sage (Kuchler 1964, Pfister et al. 1977, Thilenius 1972).

Eastern Ponderosa Pine

The eastern ponderosa pine vegetation type is a zone of savanna or open forest on breaks, foothills, and low mountain slopes in the Great Plains of southeastern Montana and northeastern Wyoming, and the Black Hills in the Dakotas. The climate is dry, and growth and establishment of ponderosa pine is slow. The mean annual precipitation in this type ranges from 12 to 18 inches, and the frost-free period is about 80 to 140 days.

Structural diversity in these communities is moderate, with generally an open overstory of ponderosa pine and occasionally Rocky Mountain juniper, an understory of grasses, and a variable shrub layer. The grass species generally are the same as in the adjacent plains; dominant species are western wheatgrass, bluebunch wheatgrass, little bluestem, blue grama, side-oats grama, prairie junegrass, needle-and-thread, and thread-leaved sedge. The shrub component is variable but often includes skunkbush sumac, prickly pear, silver sagebrush, snakeweed, chokecherry, Fendler's rose, and western snowberry. Common forbs include various species of phlox and lupine (Brown 1971, Kuchler 1964, Pfister et al. 1977, Thilenius 1972).

Great Basin-Rocky Mountain Vegetation Types (Evenly Distributed Precipitation)

There are seven vegetation types characteristic of this precipitation regime. Four of the types are dominated by shrubs or shrub-like trees; three of the types occur at higher elevations and are dominated by trees.

Mountain Mahogany-Oak Scrub

The mountain mahogany-oak scrub vegetation type is scattered on high foothills and low mountain slopes throughout Utah and western Colorado, generally occurring on sites above juniper-pinyon communities and below conifer forest. These sites typically receive between 14 and 20 inches of precipitation annually, and have a frost-free period of 80 to 140 days.

The appearance of this vegetation type generally is a thicket of tall shrubs, with relatively few forbs or grasses. The compositional diversity may be quite high, however, as numerous shrub species may be present. The typical dominants are Gambel oak, curlleaf mountain mahogany, true mountain mahogany, and bigtooth maple. Other common shrubs include Saskatoon serviceberry, Utah serviceberry, species of snowberry, chokecherry, cliffrose, greenleaf manzanita, bitterbrush, species of buckbrush, big sagebrush, Douglas rabbitbrush, ninebark, and skunkbush sumac. Although grasses and forbs contribute relatively little to community biomass, their composition may be diverse, including yarrow, pussytoes, asters, arrowleaf balsamroot, lupines, penstemons, bedstraws, blue-eyed Mary, peavine, nemophila, starry Soloman's seal, vetches, western wheatgrass, mountain brome, sedges, and wildrye (Brown 1982b, Kuchler 1964, Nixon 1967, West 1974).

Great Basin Sagebrush

This vegetation type is dominant in the Great Basin, and occurs commonly in the "four corners" area of Arizona, Colorado, New Mexico, and Utah. In the Great Basin, the type occurs on bajadas and foothill midslopes above the saline flats and below the juniper-pinyon communities at higher elevations; in the four corners area, it occurs on mesa tops and benches with gravelly soils. The mean annual precipitation in the Great Basin Sagebrush type is from 6 to 20 inches, with a frost-free period of 100 to 180 days. This type is characterized by great temperature fluctuations, both diurnally and seasonally.

The great basin sagebrush type presents a rather monotonous appearance of moderately scattered shrubs with little vegetation in the interspaces. In contrast to the sagebrush steppe in the Intermountain valleys, grasses do not contribute significantly to the community biomass. The compositional diversity may be higher than expected, however, as many species or subspecies of sagebrush are potential dominants. Community dominants usually are one of the three subspecies of big sagebrush (ssp. tridentata, wyomingensis, or vaseyana), black sage, or Bigelow sage. Other common shrubs include rubber rabbitbrush, snakeweed, winterfat, four-wing saltbush, and prickly pear. Common grasses include bluebunch wheatgrass, Indian ricegrass, squirrel tail, blue grama, galleta, sand dropseed, and various species of bluegrass. Forbs generally are of little importance but may include various species of locoweed (Kuchler 1964, Turner 1982, West 1983a).

Saltbush-Greasewood

The saltbush-greasewood vegetation type is restricted to dry intermontane basins, primarily in Utah and Colorado. These areas commonly receive only 6 to 10 inches of precipitation annually, with high evaporative demand. The rapid evaporation of water leads to accumulation of salt in the soil, which greatly restricts the number of plant species that can occupy these sites. The temperatures on these sites are extremely variable over the course of a year, with a frost-free period of 120 to 160 days.

The structural diversity of these communities is fairly low, with most sites dominated by scattered shrubs interspersed with grasses. In a given location, the compositional diversity is quite low, but species composition varies by area. Generally, the most important species is shadscale, which may be accompanied by any of several other species of saltbush. When present, greasewood often is the dominant species, but this species is more common on extremely saline soils and occurs typically in the northern end of the type. It becomes increasingly less important in the south. Other important shrubs include bud sage, winter fat, spiny hop sage, Gardner saltbush, Nuttall saltbush, and Gray Molly. Important grasses include Indian ricegrass, galleta, and alkali sacaton (Branson et al. 1976; Costello 1944; Ibrahim et al. 1972; Kuchler 1964; Turner 1982; West 1974, 1983c; West and Ibrahim 1968).

Sagebrush Steppe

The sagebrush steppe vegetation type is an important, extensive type covering vast acreages of Intermountain basins and high plains in Wyoming, southern Idaho, northern Utah, and southeast Montana. As defined here, the type includes all areas of nearly equal abundance of sagebrush and grasses (following West 1983b), and includes two of Kuchler's (1964) types, sagebrush steppe and wheatgrass-needlegrass-shrubsteppe. This area receives 6 to 14 inches of precipitation annually, but is drier than expected because much of the precipitation received as snow is lost before it melts. The frost-free period is from 80 to 140 days.

In contrast to the Great Basin sagebrush type, vegetation composition in this type is divided evenly between sagebrush and grasses; consequently, the structural diversity is somewhat higher. The compositional diversity is moderate and varies by area. Throughout the type, the dominant shrub is big sagebrush, which may be joined by fringed sagebrush, black sagebrush, budsage, shadscale, winterfat, prickly pear, and silver sage. In the western end of the type, the important grasses are bluebunch wheatgrass, Idaho fescue, Indian ricegrass, and tall native bluegrass; in the eastern end, the dominant grass species are blue grama, western wheatgrass, needle-and-thread, thread-leaved sedge, and bluebunch wheatgrass. Forbs are relatively unimportant but may include scarlet globemallow and lamb's quarter (Brown 1971, Christensen 1963, Costello 1944, Kuchler 1964, Marquiss and Lang 1959, Robertson et al. 1966, West 1983b).

Pine-Douglas-fir

Pine-Douglas-fir is a low-elevation conifer forest type prominent in the foothills and lower mountains of the Front Range of Colorado and the southern Rocky Mountains in Arizona and New Mexico. This type occurs in a moderate precipitation zone (14 to 20 inches annually) and has a frost-free period of 80 to 140 days.

The structural diversity of the type is fairly high, though variable. Low-elevation or dry sites are characterized by somewhat open stands with a grassy understory, while higher elevation or more moist sites have closed stands with a considerable shrub layer. Compositional diversity also is fairly high. In addition to ponderosa pine and Douglas-fir, other tree species on these sites can include quaking aspen, Rocky Mountain juniper, limber pine, or pinyon pine. Shrub species common on more mesic sites include common juniper, mountain ninebark, creeping holly grape, Saskatoon serviceberry, bearberry, and species of rose, currant, and raspberry. Grass and grass-like species typical of drier sites include blue grama, Arizona fescue, prairie junegrass, mountain muhly, thread-leaved sedge, and king spike-fescue. Common forbs include hairy goldaster, yarrow, and species of geranium, cinquefoil, penstemon, pussytoes, and goldenrod (Costello 1944, Kuchler 1964, Marr 1967).

Douglas-fir

The Douglas-fir vegetation type is extensive at mid-elevations throughout all of the northern and central Rocky Mountains. Generally, it covers a broad elevational band on sites that are more moist than the ponderosa pine forest below and warmer or drier than the subalpine fir sites above. This type in many areas typifies the montane environment, receiving from 20 to 35 inches of annual precipitation, with a frost-free period of 60 to 120 days.

As defined by Kuchler (1964), this is an extremely widespread type, and occurs in many areas where there are no known coal fields and where the probability of surface mining is negligible. Consequently, this description focuses on the Douglas-fir communities in south-central Montana and Wyoming, which are known to occur adjacent to coal fields.

The structural diversity of Douglas-fir communities is moderately high. Depending on soil moisture conditions, stands have moderately dense to dense overstories, with grassy, low shrub, or tall shrub understories. Compositional diversity also is high due to the large number of constituent species and potential dominants in this type. In the overstory, Douglas-fir may be joined by ponderosa pine, lodgepole pine, limber pine, or quaking aspen. Common tall shrubs include mountain ninebark, mountain maple, chokecherry, and species of gooseberry. Low shrubs include creeping holly grape, common juniper, mountain snowberry, birch-leaf spirea, species of rose, big sagebrush, Canada buffaloberry, twinflower, and bearberry. Common grasses and forbs include king spike-fescue, sheep fescue, Idaho fescue, species of bluegrass, heartleaf arnica, northern bedstraw, false Soloman's seal, weedy milkvetch, and silvery lupine (Despain 1973, Hoffman and Alexander 1976, Kuchler 1964, Pfister et al. 1977, Steele et al. 1983).

Spruce-fir

The spruce-fir is another extensive vegetation type that occurs throughout the Rocky Mountains from mid-elevation slopes to upper timberline. Kuchler (1964) divides the spruce-fir forest into two types, western spruce-fir and southwestern spruce-fir. Because the coal area of interest in Colorado and northern Arizona is near the boundary of the two types, they are here considered as one type and the focus is on only the area of interest rather than the entire Rocky Mountains. This vegetation type occurs in a precipitation zone of 20 to 45 inches, with a frost-free period of 40 to 100 days.

The spruce-fir forests are structurally diverse. They generally are closed forest, but become increasingly open toward upper timberline and often have a grass-forb layer, a low shrub layer, and a tall shrub layer. In the overstory, important species include subalpine fir, Engelmann spruce, blue spruce, white fir, Douglas-fir, and quaking aspen. Important shrubs include mountain maple, Scouler's willow, mountain gooseberry, thimbleberry, creeping holly grape, common juniper, twinflower, Canada buffaloberry, mountain snowberry, bearberry, and species of huckleberry, primarily grouse whortleberry. Common forbs include showy fleabane, strawberry, Richardson's geranium, Canada violet, and heartleaf arnica. Common grasses include fringed brome, mountain trisetum, spreading woodrush, and species of sedge (Costello 1944, Hoffman and Alexander 1976, Kuchler 1964, Moir and Ludwig 1979, Oosting and Reed 1952, Steele et al. 1983).

Southeast Area (Late-Summer Precipitation Maximum)

Three vegetation types characterize this precipitation regime.

Juniper-Pinyon

The juniper-pinyon vegetation type is one of the most extensive in the Western Coal Region, covering large areas in Utah, Colorado, Arizona, and New Mexico. This vegetation type is common on lower mountain slopes and rolling foothills throughout the specified states. It generally occurs in a precipitation zone between 8 and 16 inches, with a frost-free period of 100 to 160 days. The climate is characterized by high daytime temperatures and high evaporative demand.

The vegetation in this type is somewhat variable by area. Junipers and pinyon pines are always dominant, but the particular species can vary. In Colorado, New Mexico, and Utah, the pine generally is true pinyon pine, while in Arizona it also may be one-leaf pine. The juniper species may be still more variable, with Rocky Mountain juniper common in Colorado, northern New Mexico, and Arizona; Utah juniper common in northwest New Mexico, western Colorado, Utah, and northern Arizona; one-seeded juniper common in central and southern Arizona; and alligator juniper found in southeastern Arizona and New Mexico.

The understory is commonly dominated by shrubs interspersed with grasses. Forbs generally are few. East of the Continental Divide, the principal species may be blue grama, Indian ricegrass, galleta, Arizona fescue, big sagebrush, snowberry, and curlleaf mountain mahogany. In Utah and Arizona, common species include Indian ricegrass, needle-and-thread, ring muhly, big sagebrush, Gambel oak, prickly pear, and bitterbrush (Brown 1982a, Costello 1944, Kuchler 1964, Jameson and Reid 1965, Mason et al. 1967, Woodin and Lindsey 1954).

Blackbrush

The blackbrush vegetation type is relatively minor and occurs on nonsaline soils in the lowest and driest portions of the Colorado and Green River Basins of Utah and Arizona. This type is found in a precipitation zone of less than 8 inches annually, though yearly fluctuations can be great. The frost-free period is about 160 to 200 days, with extreme variations in diurnal and annual temperatures.

Because the environment of this vegetation type is so severe, few species other than blackbrush are found in the community. Other widely scattered shrubs may include big sagebrush, shadscale, species of joint-fir, spiny hopsage, and snakeweed. Forbs and grasses that may be present include galleta, black grama, sand dropseed, and species of gilia (Kuchler 1964, Turner 1982, West 1983b).

Grama-Galleta

The grama-galleta vegetation type is characteristic of the arid high plains of northern Arizona and New Mexico. This area receives only 8 to 12 inches of precipitation annually, and is subject to intense evaporative demand. The frost-free season is long (140 to 180 days), but the growing season may be shorter due to summer drought that induces aestivation until the late-summer rains bring on fall green-up.

The structural diversity of this type is low, as generally only a grass layer with scattered low shrubs is present. Compositional diversity also is low, as few species are adapted to the rigorous environment. The dominant species are blue grama and galleta, which are joined by black grama, side-oats grama, hairy grama, and alkali sacaton. The scattered shrubs include four-wing saltbush, species of sagebrush, winterfat, species of rose, rubber rabbitbrush, and snakeweed. High abundance of shrubs indicates overgrazing (Brown 1982c, 1982d; Kuchler 1964).

Western Washington Valley Area (Abundant Winter, Low Summer Precipitation)

The vegetation type of Kuchler (1964) in this area is probably the redcedar-hemlock-Douglas-fir forest. The predominant tree is Douglas-fir, which often is defined as subclimax in the climax western hemlock-western redcedar forest formation. The climate is humid with abundant low-intensity winter precipitation and dry summers, especially in July and August. Mean annual precipitation is about 50 inches and the frost-free period is 160 to 180 days. Winters are relatively warm and summers cool, reflecting a marine influence.

Agricultural Crops

Pastures

A common goal for reclaimed land is a vegetative cover that is diverse, effective, and permanent, and composed of species native to the area, or of introduced species where desirable and necessary to control erosion and achieve the desired postmining land use. Where pasture is the reclamation objective, the primary postmine use will be livestock grazing and sometimes hay production. Other secondary uses such as wildlife habitat, recreation, and watershed functions also are available from the reclaimed pasture. Selection of the species to use on a reclaimed pasture should be based on species adaptiveness, potential for successful establishment, forage production, and ability to provide adequate cover to protect the soil resource from excessive erosion.

One need for diversity in a plant community is to provide ecological niches for the various wildlife species that may inhabit it. Since wildlife habitat is only a secondary use of pasture land, the filling of all ecological niches is not a compelling reason for the selection of large numbers of species on reclaimed pasture. Diversity of plant species may more importantly be required for long-term vegetational stability. Enough adapted species need to be present to maintain an effective vegetative cover that is productive and able to withstand climatic fluctuations. The number of species necessary to achieve this stability often is a function of the species used and the climatic zone in which they will be growing. Ries and Hofmann (1984) compared the species composition of lightly to moderately grazed reclaimed pasture consisting of introduced species with adjacent native rangeland. Both grassland types had four major species each of which made up more than 5 percent of the total composition. The four major species made up 58 percent of the total composition on the native grassland, while the major species contributed 93 percent of the vegetation on the reclaimed pasture. The native grassland had 21 minor species that contributed 42 percent of the vegetation composition while the reclaimed pasture had only three minor species that contributed 7 percent of the vegetative composition. They interpreted their data to indicate that no additional species were needed on the reclaimed pasture to meet its intended postmine use.

Monocultures sometimes have an important role in pasture and range management. Crested wheatgrass, for example, has survived and thrived in monoculture for many years in a variety of climatic conditions. Although more diversity generally is considered preferable, a monoculture may in some cases fulfill the requirements of postmine pastures.

In selecting species for planting into a given reclaimed pasture, care must be taken to choose species that are adapted to the climatic zone, elevation, and soil characteristics of the reclaimed site. In semiarid areas, the water-holding capacity of the soil affects the composition of natural vegetation and the selection of species. In extremely arid areas, other soil and site characteristics such as slope, exposure, toxic conditions, and biotic relationships become critical. Seasonal availability of water also is of critical importance in species selection. For example, basin wild rye is well adapted to the winter-wet and summer-dry climate of the Great Basin area, but is not well adapted to the summer maximum precipitation of the Great Plains. Little bluestem, a plains species, is not well adapted to the summer droughts of the Great Basin.

Literally hundreds of species of grass could be seeded into a reclaimed pasture. Many of the native species, however, are limited by the availability of seed. A multitude of seed mixtures could be planted even for those remaining species for which a seed source is available. Packer and Aldon (1978) have listed some of the important species in the various western climatic zones. Thornburg (1982) provides more detail on important species in the major land resource areas of the West. In a given locale, the best information on specific performance and availability of seed can be obtained from the local USDA Soil Conservation Service (SCS) office or a local Extension Service office.

Some important pasture species are given below for several climatic zones in the coal mining regions of the West (Thornburg and Fuchs 1978).

Northern Great Plains

Cool-season grasses predominate in this region where the annual precipitation is between 10 and 24 inches. The native wheatgrasses—western, thickspike, bluebunch, streambank, and slender—are commonly seeded in pasture mixtures. Green needlegrass, little bluestem, big bluestem, and switchgrass also are commonly used. Prairie sandreed is adapted to sandy soils while "Garrison" creeping foxtail and reed canarygrass are adapted to wet sites. The introduced wheatgrasses—crested, intermediate, and pubescent—are commonly used in pastures in drier regions. Smooth brome and tall fescue are used for pasture in areas of higher precipitation. Alfalfa and sweetclover are the most commonly used legumes, usually seeded with grasses.

Southern Plateaus

Precipitation averages 10 to 20 inches. Among the many species that are useful in reclamation in this region are little bluestem, side-oats grama, green sprangletop, Arizona cottontop, bush muhly, plains bristle grass, vine-mesquite, blue grama, and black grama.

Intermountain Desertic Basins

Average annual precipitation is from 5 to 20 inches. Among the most commonly used species in reclamation are hard fescue and several of the wheatgrasses, including Siberian, crested, intermediate, pubescent, and tall.

Native grasses include bluebunch wheatgrass, beardless wheatgrass, big bluegrass, Idaho fescue, and Indian ricegrass. Shrubs that have performed well include fourwing saltbush and Nuttall saltbush.

Desert Southwest

Average annual precipitation in this region ranges from 5 inches or less to 10 inches. Of the grasses native to this area, big galleta and bush muhly are two that can be seeded on reclaimed land. Some of the native shrubs such as creosotebush, fourwing saltbush, and catclaw have been established.

North Pacific Valleys

Some of the species sown for pasture in this humid region are the same as those used in the humid Eastern States. These include the ryegrasses, tall fescue, orchardgrass, and subterannean clover.

Field Crops

The growing of field crops on reclaimed mining operations in the West is found almost exclusively in the Northern Great Plains, particularly in North Dakota and to a lesser extent in Montana. The most important crops are small grains. Wheat, as either spring wheat or durum, is the most important of these. Other small grains used to a lesser extent are oats, barley, and rye.

Some corn is grown in western North Dakota for silage, and recently sunflowers have become an important field crop. Other crops such as flax or safflower make up a minor portion of the total cropland area in western North Dakota.

Reclamation of mined-land has the potential to convert previously noncropped land into cropland. If a source of good water can be obtained, some reclaimed land could be irrigated. In such cases, several different crops could be grown.

Criteria for Selecting Species

Reclamation success depends on plant establishment, which, in turn, depends on selection of species that are suitable for site conditions and postmining land uses. Six major criteria for selecting plant species are discussed briefly: land use, adaptation to site, availability, genetic improvement, associated soil microorganisms, and stability and succession (see Monsen and Plummer 1978, Brown et al. 1979, Daniel et al. 1979, McArthur 1981, McKell et al. 1982, and Allen 1984).

Land Use

A knowledge of which plant species a site can support in relation to climate and soils is the most important consideration for selecting species and determining land use. In the western United States, where most of the strippable coal lies in arid to semi-arid regions, land use is limited primarily to wildlife and domestic livestock grazing (rangeland). Thus, much of the emphasis in the Western Coal Region is on returning the land to the premining condition and land use. Another important consideration is esthetics, where a landscape similar to the premine landscape is desired. Land with higher productivity potential can be returned to cultivated crops, tame pastures, and forests.

Wildlife and Livestock Grazing (Range)

Criteria to consider in selecting species for wildlife and livestock grazing include productivity, palatability and nutrition, and adaptation to grazing pressure. Use of different life forms (e.g., forbs and shrubs) will increase structural and habitat diversity for increased animal diversity.

Crop and Pasture Land

Species chosen for cultivated crop and pasture lands need to be adapted and responsive to possible fertilization and irrigation regimes. Productivity and palatability to livestock also need to be considered.

Forestry

Reforestation is the primary objective on mined land in western Washington. Forestry also may be a postmining objective also on mined lands in other states where the coal seams lie in high-elevation forested zones. Such factors as productivity and potential animal use need to be considered for a forestry land use.

Adaptation

The plant species selected need to withstand the climatic and edaphic conditions on the reclaimed mine site. In the Western Coal Region, drought is the most frequently encountered environmental extreme, but certain characteristics of the soil also may limit growth.

Both native and introduced species can be used for reclamation in the Western Coal Region. Local native species are commonly used because they are considered to be best adapted for long-term persistence and productivity. Native species can be chosen from those found on reference areas, on nearby areas with edaphic features similar to those on the reclamation site, or on old disturbances where native seral (but nonweedy) species prove to be established more readily than climax species. Introduced species are used for specific purposes such as more rapid ground cover and soil stability, increased productivity, or ability to withstand certain site conditions.

Drought Tolerance

A major reclamation problem in the Western States is that most of the mines lie in arid to semi-arid regions where moisture is limiting for seedling establishment and plant growth. Some of the characteristics of the plant that enable seedling establishment differ from those that enable survival of mature plants. Seedlings need fast production of root-surface area and quick penetration of roots to deeper soil moisture zones for increased water absorption. Drought resistance expressed in features, such as thick cuticles and osmotic adjustment, is not as well developed in seedlings as in mature plants. Under natural conditions in arid lands, seedlings probably establish during occasional years of adequate precipitation, known as the pulse phenomenon of seedling establishment. Irrigation often is used for the first 2 years to improve seedling establishment in areas receiving fewer than 10 inches of precipitation. A minimal amount of irrigation water should be used to simulate the natural pulse phenomenon and to reduce plant mortality when irrigation ceases.

The ability of established mature plants to avoid or tolerate drought needs to be considered. Criteria for choosing plants in the mature stage may include deep or extensive roots, stomatal control, leaf rolling, osmotic adjustment, and high efficiency of water use. However, it must be emphasized that the seedlings are the critical stage, and long-term survival on an arid site is not possible if plants cannot reproduce by natural seed establishment. Tubelings or cuttings seem to be less sensitive to drought than seedlings and have been used in problem areas, though to a limited extent because of greater expense. Drought hardening and deeper roots are responsible for the hardiness of tubelings and cuttings.

Seasonality of Precipitation

Seasonal precipitation patterns also are important in choosing species for a particular site. The primary choice may be between warm-season and cool-season plants. Regions that receive most of the precipitation during the summer months will support primarily warm season species. Cool-season species are adapted primarily in regions where most of the precipitation falls during the winter or the early spring months when growing temperatures are relatively cool. This generalization applies mainly to herbs and especially grasses. Some warm-season shrubs grow in areas with winter precipitation. Presumably, these shrubs are able to obtain moisture stored deep in the soil; they also are known to have cooler temperature requirements for optimum growth than most warm-season herbs.

Temperature Regime

Temperature also plays a role in site adaptation of plant species. Warm-season species require higher temperatures for optimum growth than cool season species and should be chosen for southern regions or areas where moisture is available during the hottest part of the growing season. Cool-season plants require lower temperatures for growth and should be chosen for northern regions or areas with winter-spring precipitation.

Soil Nutrients

Many western soils are low in nutrients. However, most native plants are adapted to these low nutrient regimes whereas introduced species more often have been bred and selected for soils with higher nutrient regimes. Where topsoil is replaced, fertilization may be unnecessary for species with low nutrient requirements.

Soil Toxicity

Salinity, sodicity, and high pH often are problems in arid mined lands. Occasionally, levels of boron, selenium, or other elements are higher than desired. Tolerance for specific soil conditions may be an important criterion for species selection.

Soil Texture

Although some species are adapted to a broad range of soil textures, there are some that grow best in a rather limited range of soil textures and should be chosen to reclaim areas where those soil textures cause specific problems. For instance, Indian ricegrass grows well in sandy soils, whereas western wheatgrass is found naturally and grows well in clayey soils.

Availability

Availability of seeds and planting stock was once cited as the major limitation to revegetating with native species. This is no longer as great a problem, because increased demand has led to an increased supply of many native plant materials. But the commercial availability of certain species still is limited and prices often are high.

Seed

When commercially unavailable, seeds of locally adapted ecotypes can be gathered by hand in the wild. Use of some species is hindered by this inability to process seeds; for instance, the husks or awns may be difficult to remove. Limited viability, germination, or longevity of seed are other problems that reduce the potential use of some species. Small-seeded species have been used sparingly in the past because the standard farm drill buries them so deeply that they cannot emerge. However, new technology in the development of drills that place seed at controlled depths has enabled successful planting of these seeds. An alternative is to broadcast small seeds after the large seeds have been drilled.

Planting Stock

Planting stock includes cuttings, bare-root seedlings, containerized plants, and wildlings (seedlings collected in the wild). The use of planting stock often is discouraged because of its high price relative to cost of seeding. However, planting stock may be the best choice for species that do not germinate well, or for use in certain problem areas where quick plant establishment is needed, or where relatively few plants are required or needed. The inability to propagate planting stock limits the availability of certain species. However, just as with seeds, nurseries and mine-site greenhouses currently provide a much greater variety of planting stock than in the past. Other limitations to using planting stock are related to handling and transplant stock. Stock, especially that grown indoors, should be allowed to become acclimated to the site before it is planted. Equipment to reduce the time and cost of planting is becoming available.

One source of plant material that often is available is the mature native plants growing on the mine site. These can be transplanted from an area about to be mined to one being reclaimed. A tree spade is used to transplant shrubs and small trees, while a front-end loader is used to move sod that contains grasses and forbs. This technique has the advantage of retaining species on the site that may not be available commercially. In addition, beneficial soil microorganisms are moved with the plants and need not be introduced.

Native Hay

Hay that is mowed on natural grasslands after most of the species have set seed occasionally is used to increase the species diversity on a reclaimed site, and as a mulch. The problems with native hay include a higher cost than straw mulch and a possible introduction of weed seeds. For this reason, only high-quality (relatively weed-free) native hay should be used. Seed collection on site is an alternative where certain species are not available commercially or where a local ecotype is desired.

Genetic Improvement

Another consideration in choosing a species is the potential for genetic selection and breeding to improve that species (McArthur 1981). Some native plants when initially collected in the wild have characteristics such as low germination of seed, poor seedling vigor, and slow growth that are not conducive to quick establishment and survival on a mine site.

Types of Improvement

Genetic selection and breeding programs attempt to bring about changes, such as increased germination, production, palatability, drought tolerance, and disease resistance. The characteristics that are most conducive to establishment, survival, and land use should be known when choosing improved species and varieties.

Ecotypes

Ecotypes are populations with unique genotypes suited to particular environmental regimes. It is important in genetic improvement programs to maintain a range of ecotypes so that plants that are adapted to different sites can be chosen. For instance, four-wing saltbush shows a gradient in adaptation to sites with different temperature and moisture regimes. Plants of this species from the northern United States planted at a southern site may not be adapted to the hot and dry conditions. Forestry seed zones have been established to assure the selection and use of locally adapted ecotypes of tree species (Daniel et. al 1979). Similar designations may be needed for shrubs and herbs with site-specific requirements.

Associated Soil Microorganisms

The importance of soil microorganisms in successful reclamation has become apparent from recent and past research. Plants that form mutualistic relationships with soil microorganisms are especially useful and beneficial. The classic example here is the legume-*Rhizobium* association, which is important for increased nitrogen fixation, especially for mine soils low in nitrogen. There has been a recent focus on actinorhizal and mycorrhizal associations. Actinorhizae form on a number of western shrub species and are responsible for nitrogen fixation. Mycorrhizae improve nutrient and water uptake, the latter being especially important in arid-soil situations. Where mycorrhizal fungi are absent, species with low dependence on them, such as some grass species, can be planted initially (Allen 1984). Species with a higher dependence on mycorrhizal fungi for their survival, such as most shrub and trees species, may need to be planted after the soil mycorrhizal inoculum has built up over time. Survival of trees, especially conifers on mine spoil, is precluded if they are not or do not become inoculated with ectomycorrhizal fungi. Seedlings and tubelings of tree and shrub species associated with endomycorrhizal fungi are inoculated usually by growing them in soils that are inoculated naturally with the desired fungal associates.

Stability and Succession

Stability of soils and vegetation often are the primary goals of reclamation. Where vegetation similar to the native vegetation is the goal, successional changes that lead to that goal are expected.

Soil Stability

A stable soil is one where postmining erosion is no greater than erosion on an appropriate reference area. Complete lack of erosion often is not a realistic goal in arid lands where the natural vegetation cover is sparse. To maximize protection of the watershed, it is important that soils be stabilized during the first few years following recontouring and seeding. Mulching and crimping often are used to reduce soil movement, but on some western mines, a nurse crop or standing mulch is used. Annual grains often are chosen as the nurse crop, not because they are especially adapted or will persist, but because they will disappear after a year and allow the perennial vegetation to establish. When choosing perennial species to increase soil stability, consideration must be given to the root system. Deep and spreading roots are more effective stabilizers than shallow, short-root systems.

Stability of Vegetation

For postmining land uses, the stability of vegetation can be defined as persistence of a canopy cover that is similar in extent to a reference area, combined with persistence of a desired species composition. The plants must be able to reproduce by seeds or vegetatively for long-term persistence, so species must be chosen for their ability to reproduce in a given environment. Changes in species composition over time, or by succession, are expected if the site is to simulate a native plant community. It is important that a compatible mixture of species be chosen so that, for instance, one highly productive or aggressive species does not dominate the site. It may be desirable to encourage colonization by native species from outside the site for increased diversity.

Plant Species for Revegetating Surface-Mined Sites

The following species in Table 24 are alphabetized by common name within life forms (i.e., grasses, sedges, forbs, shrubs, and trees). Species referred to in the text are included in this list. In addition, a detailed description follows for species indicated. These are species most recommended for appropriate sites.

Table 24. Plant species for revegetating coal surface-mined lands in the Western Region. Detailed information on those species in bold face type is given on the following pages of this chapter.

Common Name	Scientific Name and Authority*
	GRASSES
Alkali sacaton	*Sporobolus airoides* (Torr.) Torr.
Annual ryegrass	*Lolium multiflorum* Lam.
Arizona cottontop	*Trichachne californic* (Benth.) Chase
Arizona fescue	*Festuca arizonica* Vasey
Barley	*Hordeum vulgare* L.
Basin wild-rye	*Elymus cinereus* (Scribn. & Merr.)
Beardless wheatgrass	*Agropyron inerme* (Scribn. & Smith) Rydb.
Big bluegrass	*Poa ampla* Merr.
Big bluestem	*Andropogon gerardi* Vitman.
Big galleta	*Hilaria rigida* (Thurb.) Benth.
Black grama	*Bouteloua eriopoda* (Torr.) Torr.
Blue grama	*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.
Blue panicgrass	*Panicum antidotale* Retz.
Blue wild-rye	*Elymus glaucus* Buckl.
Bluebunch wheatgrass	*Agropyron spicatum* (Pursh) Scribn. & Smith
Bluegrass	*Poa* spp.
Buffalograss	*Buchloe dactyloides* (Nutt.) Engelm.
Buffelgrass	*Pennisetum ciliare* (L.) Link
Bush muhly	*Muhlenbergia porteri* Scribn.
Caucasian bluestem	*Bothriochloa Caucasica* (Trin.) C.E. Hubb
Corn	*Zea mays* L.
Crested wheatgrass	*Agropyron desertorum* (L.) Gaertn.
False melic	*Schizachne purpurascens* (Torr.) Swallen
Fringed brome	*Bromus ciliatus* L.
Galleta	*Hilaria jamesii* (Torr.) Benth.
Garrison creeping foxtail	*Alopecurus arundinaceus* Poir.
Green needlegrass	*Stipa viridula* Trin.
Green sprangletop	*Leptochloa dubia* (H.B.K.) Nees.
Hard fescue	*Festuca ovina duriuscula* (L.) Koch
Hairy grama	*Bouteloua hirsuta* Lag.
Idaho fescue	*Festuca idahoensis* Elmer
Indian ricegrass	*Oryzopsis hymenoides* (Roem. & Schult.) Ricker
Indiangrass	*Sorghastrum nutans* (L.) Nash
Intermediate wheatgrass	*Agropyron intermedium* (Host.) Beauv.
King spike-fescue	*Hesperochloa kingii* (S. Wats.) Rydb.
Kleingrass	*Panicum coloratum* L.
Little bluestem	*Schizachyrium scoparius* (Michx.) Nash
Mountain brome	*Bromus marginatus* Nees.
Mountain muhly	*Muhlenbergia montana* (Nutt.) Hitchc.
Mountain trisetum	*Trisetum montanum* Vasey
Needle-and-thread	*Stipa comata* Trin. & Rupr.
Oats	*Avena sativa* L.
Orchardgrass	*Dactylis glomerata* L.
Perennial ryegrass	*Lolium perenne* L.
Plains bristlegrass	*Setaria macrostachya* (H.B.K.)
Porcupine grass	*Stipa spartea* Trin.
Prairie junegrass	*Koeleria cristata* (L.) Pers.
Prairie sandreed	*Calamovilfa longifolia* (Hook.) Scribn.
Pubescent wheatgrass	*Agropyron trichophorum* (Link.) Richt.
Reed canarygrass	*Phalaris arundinacea* L.
Ring muhly	*Muhlenbergia torreyi* (Kunth) Hitchc. ex Bush
Rough hairgrass	*Agrostis scabra* Willd.
Rough-leaved ricegrass	*Oryzopsis asperifolia* Michx.
Rye	*Secale cereale* L.
Sand bluestem	*Andropogon hallii* Hack.
Sand dropseed	*Sporobolus cryptandrus* (Torr.) A. Gray
Sand lovegrass	*Eragrostis trichodes* (Nutt.) Wood
Sandberg bluegrass	*Poa secunda* Presl.
Sheep fescue	*Festuca ovina* L.
Siberian wheatgrass	*Agropyron sibiricum* (Willd.) Beauv.
Side-oats grama	*Bouteloua curtipendula* (Michx.) Torr.
Slender wheatgrass	*Agropyron trachycaulum* (Link) Malte
Smooth brome	*Bromus inermis* Leyss
Squirreltail	*Sitanion hystrix* (Nutt.) J.G. Smith
Streambank wheatgrass	*Agropyron riparium* Scribn. & Smith
Switchgrass	*Panicum virgatum* L.
Tall fescue	*Festuca arundinacea* Schreb.
Tall native bluegrass	*Poa fendleriana* Nutt.
Tall wheatgrass	*Agropyron elongatum* (Host) Beauv.
Thickspike wheatgrass	*Agropyron dasystachyum* (Hook.) Scribn.
Thickstem wheatgrass	*Agropyron dasystachyum* (Hook.) Scribn.
Timber oatgrass	*Danthonia intermedia* Vasey
Timothy	*Phleum pratense* L.
Vine-mesquite	*Panicum obtusum* H.B.K.
Western wheatgrass	*Agropyron Smithii* Rydb.
Wheat	*Triticum aestivum* L.
Yellow bluestem	*Andropogon ischaemum* L.
Yellow Indiangrass	*Sorghastrum nutans* (L.) Nash

*Names and authorities mostly follow Terrell 1977 and Little 1979. Another source is L. H. Bailey Hortorium 1976.

Table 24. Plant species for revegetating coal surface-mined lands in the Western Region. Detailed information on those species in bold face type is given on the following pages of this chapter.

Common Name	Scientific Name and Authority*
GRASS-LIKES	
Narrow-leaved sedge	*Carex muricata* L.
Spreading woodrush	*Luzula divaricata* Wats.
Thread-leaved sedge	*Carex filifolia* Nutt.
FORBS	
Alfalfa	*Medicago sativa* L.
American vetch	*Vicia americana* Muhl.
Arrowleaf balsamroot	*Balsamorhiza sagittata* (Pursh) Nutt.
Aster	*Aster* spp.
Bedstraw	*Galium* spp.
Birdsfoot trefoil	*Lotus corniculatus* L.
Blazing star	*Liatris punctata* Hook.
Blue-eyed mary	*Collinsia parviflora* Lindl.
Canada violet	*Viola canadensis* L.
Cicer milkvetch	*Astragalus cicer* L.
Cinquefoil	*Potentilla* spp.
Cream-flowered peavine	*Lathyrus ochroleucus* Hook.
Crownvetch	*Coronilla varia* L.
Drummond's milk-vetch	*Astragalus drummondii* Hook.
False Soloman's seal	*Smilacina racemosa* (L.) Desf.
Flax	*Linum usitatissimum* L.
Geranium	*Geranium* spp.
Goldenrod	*Solidago* spp.
Gooseberry globemallow	*Sphaeralcea grossulariaefola* (H.&A.) Rydb.
Gumweed	*Grindelia squarrosa* (Pursh) Dunal
Hairy goldaster	*Chrysopsis villosa* (Pursh) Nutt.
Heartleaf arnica	*Arnica cordifolia* Hook.
Illinois bundleflower	*Desmanthus illinoensis* (Michx.) MacM.
Joint-fir	*Ephedra* spp.
Lamb's quarter	*Chenopodium album* L.
Lewis flax	*Linum lewisii* Pursh
Little sunflower	*Helianthus pumilus* Nutt.
Lupine	*Lupinus* spp.
Maximillian sunflower	*Helianthus maximiliani* Schrad.
Nemophila	*Nemophila* spp.
Northern bedstraw	*Galium boreal* L.
Northern sweetvetch	*Hedysarum boreale* Nutt.
Peavine	*Lathyrus* spp.
Penstemon	*Penstemon* spp.
Phlox	*Phlox* spp.
Prairie sage	*Artemisia ludoviciana* Nutt.
Purple prairie clover	*Petalostemon purpureum* (Vent.) Rydb.
Pussytoes	*Antennaria* spp.
Richardson's geranium	*Geranium richardsonii* Fisch. & Trautv.
Rocky mountain penstemon	*Penstemon strictus* Benth.
Safflower	*Carthamus tinctorius* L.
Sainfoin	*Onobrychis viciaefolia* Scop.
Scarlet globemallow	*Sphaeralcea coccinea* (Nutt.) Rydb.
Showy fleabane	*Erigeron superbus* Greene ex Rydb.
Showy sunflower	*Helianthus rigidus* (Cass.) Desf.
Silvery lupine	*Lupinus argenteus* Pursh
Small burnet	*Sanguisorba minor* Scop.
Starry Soloman's seal	*Smilacina stellata* (L.) Desf.
Strawberry	*Fragaria* spp.
Subterranean clover	*Trifolium subterraneum* L.
Sunflower	*Helianthus* spp.
Sweetclover	*Melilotus* spp.
Vetch	*Vicia* spp.
Violet	*Viola* spp.
Wartberry fairybell	*Disporum trachycarpum* (Wats.) Benth. & Hook.
Weedy milkvetch	*Astragalus miser* Dougl.
Western yarrow	*Achillea millefolium lanulosa* (Nutt.) Piper
White clover	*Trifolium repens* L.
White sweetclover	*Melilotus alba* Desr.
Wooly Indian-wheat	*Plantago purshii* Roem. & S.A. Schultes
Yarrow	*Achillea millefolium* L.
Yellow sweetclover	*Melilotus officinalis* (L.) Lam.
SHRUBS	
Antelope bitterbrush	*Purshia tridentata* (Pursh) DC.
Apache-plume	*Fallugia paradoxa* (D. Don) Endl.
Arkansas rose	*Rosa arkansana* Porter
Atriplex (saltbush)	*Atriplex* spp.
Bearberry	*Arctostaphylos uva-ursi* (L.) Spreng.
Big sagebrush	*Artemisia tridentata* Nutt.
Bigelow sage	*Artemisia bigelovii* Gray
Bigtooth maple	*Acer grandidentatum* Nutt.
Birch-leaf spirea	*Spiraea betulifolia* Pall.
Bitterbrush	*Purshia tridentata* (Pursh.) DC.
Black greasewood	*Sarcobatus vermiculatus* (Hook.) Torr.
Black sagebrush	*Artemisia arbuscula* var. *nova* (A. Nels.) Cronq.
Blackbrush	*Coleogyne ramosissima* Torr.
Buckbrush	*Ceanothus* spp.
Budsage	*Artemisia spinescens* (DC.) Eat.
Canada buffaloberry	*Shepherdia canadensis* (L.) Nutt.
Catclaw acacia	*Acacia greggii* A. Gray
Chokecherry	*Prunus virginiana* L.
Cliffrose	*Cowania stansburiana* Torr.
Common juniper	*Juniperus communis* L.
Creeping hollygrape	*Berberis repens* Lindl.
Creosotebush	*Larrea divaricata* Cav.
Cuneate saltbush	*Atriplex cuneata* A. Nels.
Curlleaf mountain-mahogany	*Cercocarpus ledifolius* Nutt.

*Names and authorities mostly follow Terrell 1977 and Little 1979. Another source is L. H. Bailey Hortorium 1976.

Table 24. Plant species for revegetating coal surface-mined lands in the Western Region. Detailed information on those species in bold face type is given on the following pages of this chapter.

Common Name	*Scientific Name and Authority**
SHRUBS, continued	
Currant (gooseberry)	*Ribes* spp.
Desert bitterbrush	Purshia glandulosa
Douglas rabbitbrush	*Chrysothamnus viscidiflorus* (Hook.) Nutt.
Fendler's rose	*Rosa woodsii* var. *Fendleri* Rydb.
Four-wing saltbush	*Atriplex canescens* (Pursh.) Nutt.
Fringed sagebrush	*Artemisia frigida* Willd.
Gambel oak	*Quercus gambelii* Nutt.
Gardner saltbush	Atriplex gardneri (Moq.) Standl.
Gilia	*Gilia* spp.
Golden currant	*Ribes aureum* Pursh.
Gray molly summer cypress	*Kochia americana* var. *Vestita* S. Wats.
Green ephedra	*Ephedra viridis* Coville.
Greenleaf manzanita	*Arctostaphylos patula* Greene
Grouse whortleberry	*Vaccinium scoparium* Leiberg
Huckleberry	*Vaccinium* spp.
Leadplant amorpha	*Amorpha canescens* Pursh.
Longleaf snowberry	*Symphoricarpos longiflorus* Gray
Martin ceanothus	*Ceanothus martinii* M. E. Jones
Mat saltbush	*Atriplex corrugata*
Mexican cliffrose	*Cowania mexicana* Don.
Mountain gooseberry	*Ribes montigenum* McClatchie
Mountain maple	*Acer glabrum* Torr.
Mountain ninebark	*Physocarpus monogynus* (Torr.) Coult.
Ninebark	*Physocarpus malvaceus* (Greene) Kuntze
Nuttall saltbush	*Atriplex nuttallii* Wats.
Prickly pear	*Opuntia polyacantha* Haw.
Prostrate kochia or prostrate summer-cypress	*Kochia prostrata* (L.) Schrad.
Raspberry	*Rubus* spp.
Rose	*Rosa* spp.
Rubber rabbitbrush	*Chrysothamnus nauseosus* (Pall.) Britt.
Sagebrush	*Artemisia* spp.
Saskatoon serviceberry	*Amelanchier alnifolia* Nutt.
Scouler's willow	*Salix scouleriana* Barratt
Shadscale	*Atriplex confertifolia* (Torr. & Frem.) S. Wats.
Shrubby cinquefoil	*Potentilla fruticosa* L.
Siberian pea shrub	*Caragana arborescens* Lam.
Silver buffaloberry	*Shepherdia argentea* (Pursh) Greene.
Silver sagebrush	*Artemisia cana* Pursh.
Skunkbush sumac	*Rhus trilobata* Nutt.
Snakeweed	*Xanthocephalum sarothrae* (Pursh) Shinners
Snowberry	Symphoricarpos spp.
Spineless hopsage	*Grayia brandegei*
Spiny hopsage	*Grayia spinosa* (Hook.) Moq.
Spiny sagebrush or bud sage	*Artemisia spinescens* (DC.) Eat.
Thimbleberry	*Rubus parviflorus* Nutt.
True mountain mahogany	*Cercocarpus montanus* Raf.
Twinflower	*Linnaea borealis* L.
Utah serviceberry	*Amelanchier utahensis* Koehne
War currant or squaw currant	*Ribes cereum* Dougl.
Western snowberry	*Symphoricarpos occidentalis* Hook.
Western virginsbower	*Clematis ligusticifolia* Nutt.
Winterfat	*Ceratoides lanata* (L.) C.A. Mey. (Eurotia lanata)
Woods rose	*Rosa woodsii* Lindl.
TREES	
Alligator juniper	*Juniperus deppeana* Steud.
Arizona cypress	Cupressus Arizonica Greene
Bigtooth maple	*Acer grandidentatum* Nutt.
Blue spruce	*Picea pungens* Engelm.
Bur oak	*Quercus macrocarpa* Michx.
Desert willow	*Chilopsis Linearis* (Cav.) Sweet
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco
Engelmann spruce	*Picea engelmannii* Parry
Green ash	Fraxinus pennsylvanica Marsh.
Limber pine	*Pinus flexilis* James
Lodgepole pine	*Pinus contorta* Dougl.
New Mexico locust	*Robinia neomexicana* A. Gray
One-leaf pine	*Pinus monophylla* Torr. & Frem.
One-seeded juniper	*Juniperus monosperma* (Engelm.) Sarg.
Paper birch	*Betula papyrifera* Marsh.
Pinyon pine	*Pinus edulis* Engelm.
Ponderosa pine	*Pinus ponderosa* Laws.
Quaking aspen	*Populus tremuloides* Michx.
Rocky Mountain juniper	*Juniperus scopulorum* Sarg.
Rocky Mountain maple	*Acer glabrum* Torr.
Russian olive	*Elaeagnus Angustifolia* L.
Subalpine fir	*Abies lasiocarpa* (Hook.) Nutt.
Utah juniper	*Juniperus osteosperma* (Torr.) Little
White fir	*Abies concolor* (Gord. & Gled.) Lindl.

*Names and authorities mostly follow Terrell 1977 and Little 1979. Another source is L. H. Bailey Hortorium 1976.

Species Descriptions

GRASSES

ALKALI SACATON
(*Sporobolus airoides* (Torr.) Torr.)

Propagation/Reproduction:
- Natural: Season of growth April-October. Matures in August.
- Artificial Establishment: Poor to fair from seed. Improves with supplemental irrigation. Very good for transplanting. Planting season: late fall, early spring, winter.
- Colonizing Ability: Fair persistence, tillers well in moist conditions. Natural spread is good.
- Habit: Coarse, densely tufted bunchgrass. Warm season. Height of seed stalk about 90 cm (3 ft). Spread 20 to 45 cm (8 to 18 in) long (basal). Coarse fibrous roots, good rooting depth.

Habitat:
- Soil: Clayey soils, poor in sandy conditions.
- Distribution: Intermountain West, saline bottomlands.
- Precipitation Range: 15 to 46 cm (6 to 18 in).
- Tolerances: Tolerant of drought, flooding and saline-alkaline conditions. Moderately tolerant to close grazing.

Uses: Erosion control, grazing, and wildlife. Poor winter forage, palatable summer growth, spring growth has poor palatability.

Comments: Use local seed source, closely cropped grass affords good grazing.

BASIN WILD-RYE
(*Elymus cinereus* Scribn. & Merr.)

Propagation/Reproduction:
- Artificial Establishment: Readily established from seed.
- Colonizing Ability: Competitive against weeds, slightly spreading.
- Habit: Cool season, bunchgrass. Up to 3 m tall (10 ft). Leaves flat and coarse up to 2 ft long. Extensive root system with short, thick, perennial root stocks.

Habitat:
- Soil: Medium to fine textures, dry to wet conditions. Moist preferred.
- Distribution: All Western States.
- Tolerances: Fair to good flooding. Fair drought, fair to good saline, low tolerance to close grazing, moderately tolerant to shade.

Uses: Grazing, erosion control, hay, cover for upland game birds, wildlife. Moderate palatability.

Comments: Numerous varieties; moderate, early grazing is essential to good stands. Best adapted to wet winter, dry summer climates.

BIG BLUEGRASS
(*Poa ampla* Merr.)

Propagation/Reproduction:
- Natural: Growth begins in very early spring. Matures in early summer at lower elevations.
- Artificial Establishment: Fair ease of establishment. Can be transplanted. Moderate seedling vigor.
- Colonizing Ability: Fair persistence. Very good rate of natural spread. Moderate competitor.
- Habit: Cool season, bunchgrass. Tufted. 60 to 120 cm (2 to 4 ft) tall. Leaf blades are pale green, flat and 20 to 40 cm (8 to 16 in) long. Deep, fibrous root system.

Habitat:
- Soil: Loamy sand to loamy clay textures. Slightly acid to slightly alkaline soils.
- Distribution: All Western States
- Precipitation Range: > 30 cm (> 12 in).
- Tolerances: Moderate drought, poor salt, poor high water table, moderate shade and grazing.

Uses: Grazing, wildlife.

BIG BLUESTEM
(*Andropogon gerardi* Vitman)

Propagation/Reproduction:
- Natural: Growth starts in late spring and continues through summer. Seed matures in late September or October.
- Artificial Establishment: Fair to difficult ease of establishment from seed. Restricted to mesic sites. Prefers moist conditions.
- Colonizing Ability: Rhizomatous. Seldom produces seed yearly. Requires plentiful moisture and moderate temperatures during bloom.
- Habit: Warm season, up to 2 m (6 ft) tall. Leaf blades 30 cm (12 in). Deep, extensive root systems, sod former.

Habitat:
- Soil: Adapted to all soil types. Prefers moist, well-drained loams.
- Distribution: Great Plains, central and southern Rocky Mountains.
- Precipitation Range: > 40 cm (> 15 in).
- Tolerances: Fair tolerance to flooding, fair drought, poor to fair salt tolerance.

Uses: Grazing, native hay. Erosion control. Use in reclamation is limited to favorable sites.

Comments: Several varieties. Use adapted seed source.

BLUE GRAMA

(*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.)

Propagation/Reproduction:

Natural: Seed matures in August. Growth begins in late spring. Seed ripens rapidly near maturity.

Artificial Establishment: Ease of establishment is poor to good; seems to depend on available moisture and use of adapted seed. Can be drilled or broadcast.

Colonizing Ability: Spreads by tillering, relatively persistent, competes well after establishment.

Habit: Warm season, bunchgrass, leaves 8 to 15 cm (3 to 6 in). Flowering stems are 30 to 45 cm (12 in to 18 in) tall. Becomes sod former under heavy grazing.

Habitat:

Soil: All soils, prefers loamy to clayey textures.

Elevation: $>$ 1,250 m ($>$ 4,000 ft).

Distribution: Northern and Central Great Plains, central and southern Rocky Mountains, northern and central Intermountain Desert Basins, Southern Plateaus (West Texas to Montana to eastern Utah and Arizona).

Precipitation Range: 20 to 50 cm (8 to 20 in).

Tolerances: Very good drought, fair salinity, poor flooding on high water table.

Uses: Important range species, erosion control. High forage value in winter and summer. Wildlife.

Comments: Use adapted seed sources. Noted varieties include Lovington, NM-118, Woodward.

BLUEBUNCH WHEATGRASS

(*Agropyron spicatum* (Pursh) Scribn. & Smith)

Propagation/Reproduction:

Natural: Growth begins in early spring dependent on moisture. Seed ripens July through August.

Artificial Establishment: Propagated by seed only. Prominent divergent awns must be removed for handling in seed drills. Grazing at seed maturity for scattering is successful.

Colonizing Ability: Climax herbaceous species of the Pacific Northwest and Intermountain Regions. Good rate of natural spread.

Habit: Cool season bunchgrass. Up to 1.3 m (4 ft) tall. Leaves are 15 to 25 cm (6 to 10 in) long. Midgrass. Seed heads 15 cm (6 in) long.

Habitat:

Soil: Sandy loam to clay loam. Shallow and gravelly. Calcareous.

Elevation: $<$ 2,700 m ($<$ 8,500 ft).

Distribution: Northern Great Plains, north and central Rocky Mountains, Palouse Prairie, Columbia Basin and Plateau, Snake River Plain, Great Basin Intermontane, northern and central Intermountain, Cascade-Sierra Nevada.

Precipitation Range: 12 to 50 cm (5 to 20 in); optimum $\geq$ 30 cm (12 in).

Tolerances: Good drought, fair salt, poor flooding or high water table. Low to close grazing.

Uses: Erosion control, wildlife, and grazing. High palatability. Abundant.

Comments: Generally adapted to sagebrush foothill and Pinyon-Juniper areas. Seed production in natural stands is erratic and depends on moisture and cool temperatures during the bloom.

BUFFALOGRASS

(*Buchloe dactyloides* (Nutt.) Engelm.)

Propagation/Reproduction:

Natural: Growth begins in late spring and continues through summer until October. Seed ripens from June through September.

Artificial Establishment: Moderate ease of establishment. Propagated by seed or sod transplant. Plants are unisexual. Customary to plant 10 females to 1 male. Seed is enclosed in burs. Soaking, chilling, and processing improves germination.

Colonizing Ability: Spreads rapidly by surface runners. Aggressive and persistent under heavy use.

Habit: Warm season, sod former. Short grass. 10 to 15 cm (4 to 6 in) tall. Leaves narrow and 8 to 15 cm (3 to 6 in) long. Forms dense, matted turf.

Habitat:

Soil: Prefers loamy and clayey textures. Not suited for sands.

Distribution: Great Plains, Southern Plateaus (New Mexico and Arizona)

Tolerances: Good drought, fair salt, fair to good high water table. Tolerant to grazing.

Uses: Valuable forage species but low production. Erosion control and wildlife. Lawn and recreation in arid areas.

Comments: Recommended for seed mixtures only. Noted varieties are Texoka and mesa.

CRESTED WHEATGRASS

(*Agropyron desertorum* (L.) Gaertn.)

Propagation/Reproduction:

Natural: Season of growth begins in early spring. Matures in early to midsummer. Fair regrowth in fall with moisture.

Artificial Establishment: Easily established from seed. Good germination. Chilling or soaking in water improves germination.

Colonizing Ability: Long-lived. Good persistence where growing season is less than 120 days. Moderate to highly competitive. Good seedling vigor.

Habit: Cool season, bunchgrass. Midgrass. Culms 30 to 100 cm (1 to 3 ft) tall. Deep, finely branched, fibrous root system.

Habitat:

Soil: All textures, prefers moderately deep, loamy soils. Slightly acid to moderately alkaline.

Elevation: 1,500 m to 2,700 m (5,000 to 9,000 ft).

Distribution: Montana, Wyoming, western edge of Dakotas, Colorado, Utah, Idaho. Parts of Arizona and New Mexico.

Precipitation Range: 20 to 45 cm (8 to 18 in).

Tolerances: Good drought, fair salt, poor to fair high water table. Moderate shade.

Uses: Commonly used for roadside stabilization, upland bird cover, grazing and hay. Good palatability. Similar species are crested wheatgrass (Fairway) (*A. cristatum*) and Siberian wheatgrass (*A. sibiricum*). Both introduced. Slight differences in appearances and adapted habitats.

GALLETA

(*Hilaria jamesii* (Torr.) Benth.)

Propagation/Reproduction:

Natural: Season of growth begins with spring moisture. May produce 2 seed crops, 1st in June, 2nd from August to October depending on moisture.

Artificial Establishment: May be difficult to establish. Reports vary from poor to good for seed germination.

Colonizing Ability: Rhizomatous spreading grass. Long-lived. Good persistence.

Habit: Warm season, bunchgrass, sod former. Erect 8 to 50 cm (3 to 20 in) tall. Deep spreading root system.

Habitat:

Soil: Coarse to fine textures. Basic and saline.

Elevation: 1,500 to 2,100 m (5,000 to 7,000 ft).

Distribution: Wyoming to California, south to New Mexico and Arizona.

Precipitation Range: $\rangle$ 10 cm (4 in).

Tolerances: Good drought, fair salt, poor to fair high water table. Good grazing after establishment. Winter-hardy. Poor shade tolerance.

Uses: Grazing, erosion control, and wildlife. Incompatible with grama grasses.

GREEN NEEDLEGRASS

(Feather Bunchgrass) (*Stipa viridula* Trin.)

Propagation/Reproduction:

Natural: Growth starts in early spring and continues through fall depending on available moisture. Seed matures in early July.

Artificial Establishment: Propagate by seed or transplanting. Seed should be scarified or dry stored for 1 year prior to planting. Average ease of establishment.

Colonizing Ability: Good persistence. Excellent seedling vigor and high resistance to disease and insects.

Habit: Cool season, bunchgrass. Midgrass. Up to 1 m (3 ft) tall. Leaves mostly basal, 20 to 30 cm (8 to 12 in) long. Awns on seeds. Deep, fibrous root system.

Habitat:

Soil: Sandy loams to clays. Prefers loams and clay loams.

Distribution: Northern and Central Great Plains, central Rocky Mountains, Great Basin Intermontane, northern and central Intermountain Basins.

Precipitation Range: 30 to 50 cm (12 to 20 in).

Tolerances: Fair to good drought, fair salt, fair high water table, moderate shade tolerant, moderate to grazing.

Uses: High forage quality with good yield. High value to songbirds and rodents. Native grass hay.

Comments: Varieties include Green Stipa grass, Lodorm. Seldom occurs in pure stands except where additional moisture is supplied or abandoned croplands.

IDAHO FESCUE

(*Festuca idahoensis* Elmer)

Propagation/Reproduction:

Natural: Growth begins in March or April. Matures in mid to late summer.

Artificial Establishment: Fair ease of establishment. Can be transplanted. Seedling vigor is fair. Stands develop 2nd or 3rd year.

Colonizing Ability: Mature plants strong competitors. Seedlings are weak. Poor seed production. Good persistence.

Habit: Cool season, bunchgrass. Upright culms 30 to 100 cm (1 to 3 ft) tall. Numerous fine basal leaves with narrow inrolled blades. Dense, fibrous root system.

Habitat:

Soil: Sandy loam to clay loam textures.

Elevation: 250 to 3,600 m (800 to 12,000 ft).

Distribution: West of Rocky Mountains.

Precipitation Range: 25 to $>$ 50 cm (10 to $>$ 20 in). Prefers $>$ 37 cm (15 in).

Tolerances: Moderate drought, moderate salt, poor high water table or flooding, moderate grazing.

Uses: Grazing, soil stabilization. Similar native species are Arizona Fescue (*F. arizonica*) and sheep fescue (*F. ovina*). Introduced species is hard fescue (*F. Ovina duriuscula*).

INDIAN RICEGRASS

(*Oryzopsis hymenoides* (Roemer & Schultes) Ricker.)

Propagation/Reproduction:

Natural: Vegetative division in fall or early spring.

Artificial Establishment: Seed needs scarification, plant seed shallow.

Colonizing Ability: Typically one of the first species to become established on sandy sites.

Habit: Height: 30 to 50 cm (12 to 20 in). Spread: 20 to 30 cm (8 to 12 in). Bunchgrass with deep, fibrous root system. Cool season.

Habitat:

Soil: Sandy to medium textures, shallow.

Elevation: 610 to 3,050 m (2,000 to 10,000 ft).

Distribution: Western United States.

Precipitation Range: 10 to 30 cm (4 to 12 in).

Tolerances: Fair salt and drought tolerance.

Uses: Excellent forage, good erosion control. Dove use seed.

Comments: Considerable ecotypic variation. Adapted seed sources should be used.

INDIANGRASS (Yellow Indiangrass)
(*Sorghastrum nutans* (L.) Nash)

Propagation/Reproduction:
Natural: Growth begins in mid to late spring. Matures in late summer or fall.
Artificial Establishment: Easily established from seed. Seedlings have good vigor. Can be transplanted by sprigs. Stands form quickly.
Colonizing Ability: Decreases with grazing use. Spreads by seed and possibly rhizomes.
Habit: Warm season, bunching, sod former. Culms 100 to 160 cm (3 to 5 ft) tall. Short scaley rhizomes. Leaf blades wide, flat, and up to 60 cm (2 ft) long.

Habitat:
Soil: Fine sand to clay loam textures.
Elevation: $<$ 2,100 m ($<$ 7,000 ft).
Distribution: Eastern Montana and Wyoming, Colorado (except northwest corner), New Mexico, and northeastern half of Arizona.
Precipitation Range: $>$ 40 cm ($>$ 16 in).
Tolerances: Fair drought, moderate salt, good on periodic or brief flooding.

Uses: Grazing, wildlife, erosion control. Good palatability.

INTERMEDIATE WHEATGRASS
(*Agropyron intermedium* (Host.) Beauv.)

Propagation/Reproduction:
Natural: Season of growth begins in early spring. Matures in mid to late summer.
Artificial Establishment: Easily established from seed. Prechilling and soaking in water hastens germination. Strong seedling vigor. Moderate grazing essential once established. Can be sodded.
Colonizing Ability: Medium longevity. Aggressive spread from rhizomes and seed.
Habit: Cool season, open, sod former. Erect culms 60 to 130 cm (2 to 4 ft) tall. Clumped, basal leaves and short spreading rhizomes. Dense mat of roots and rhizomes at surface and deep, extensive fibrous roots.

Habitat:
Soil: Sandy loams to clay loams. Prefers finer textures. Slightly acid to basic reaction.
Elevation: 300 to 3,000 m (1,000 to 10,000 ft).
Distribution: Dakotas, Nebraska west to Sierra Nevadas. From northern New Mexico and Arizona to Canada.
Precipitation Range: 32 to $>$ 50 cm (13 to $>$ 20 in).
Tolerances: Fair drought, fair salt, fair high water table (at 3 ft) and short-term flooding.

Uses: Pasture, hay, soil stabilization. Wildlife plantings.
Varieties: Amur, Greenar, Oahe, Tegmar, Slate, Chief.

LITTLE BLUESTEM
(*Schizachyrium scoparius* (Michx.) Nash)

Propagation/Reproduction:
Natural: Growth begins in late spring and continues through summer. Seed matures in late September and October.
Artificial Establishment: Fair ease of establishment. Propagate by seed. No information on transplanting. "Trashy" seed requires cleaning before use in seed drills.
Colonizing Ability: Spreads by seed and tillers. Vigorous and long-lived.
Habit: Warm season, bunchgrass. Midgrass. Usually 30 cm to 1 m (1 to 3 ft) tall. Leaf blades 10 to 20 cm (4 to 8 in) long. Dense root system.

Habitat:
Soil: All soils most common on well-drained, coarse to loamy textures. Shallow and calcareous soils.
Elevation: Range not determined. $<$ 1,982 m (6,500 ft) reported.
Distribution: Great Plains, central and southern Rocky Mountains, and Southern Plateaus.
Precipitation Range: 30 to $>$ 50 cm (12 to $>$ 72 in). Best at $>$ 40 cm (16 in).
Tolerances: Fair to good drought, poor salt, fair high water table.

Uses: Grazing, excellent erosion control, wildlife. Palatability and forage quality decrease as plant matures.

Comments: In native stands, seed development depends on favorable moisture and temperatures.

MOUNTAIN BROME
(*Bromus marginatus* Nees)

Propagation/Reproduction:
Natural: Season of growth not determined.
Artificial Establishment: Easily established by seed. Easily transplanted.
Excellent seedling vigor. Prechill seeds.
Colonizing Ability: Short-lived (3 to 5 years). Good spread by seed. Moderate persistence.
Habit: Cool season, bunchgrass. Culms 30 to 130 cm (1 to 4 ft) tall. Coarse basal and cauline leaves. Tufted with fibrous shallow roots.

Habitat:
Soil: Sandy to clay loam textures.
Elevation: 1,500 to 3,000 m (5,000 to 10,000 ft).
Distribution: All western States.
Precipitation Range: $>$ 45 cm ($>$ 18 in).
Tolerances: Weakly moderate drought, fair salt, poor high water table.

Uses: Revegetating rangelands, wildlife. Surface covering for erosion control. Good palatability.

NEEDLE AND THREAD
(*Stipa comata* Trin. & Rupr.)

Propagation/Reproduction:
- Natural: Growth begins in early spring and continues through summer. Growth resumes after drought. Flowers in June, seed matures in July.
- Artificial Establishment: Moderate ease of establishment. Propagate by seed. No information on transplanting. Awns on seeds create handling difficulties with drills.
- Colonizing Ability: Exists in almost pure stands as an invader on abandoned disturbed lands.
- Habit: Cool season, bunchgrass. Midgrass. Seed stalks 30 cm to 1.3 m (1 to 4 ft) tall. Leaves are narrow and 20 to 30 cm (8 to 12 in) long. Awns average 15 cm (6 in) long. Deep rooted.

Habitat:
- Soil: Coarse to coarse loamy textures. Shallow and calcareous soils.
- Distribution: Northern and Central Great Plains, Rocky Mountain States. Intermountain areas, east of Sierra Nevadas and Cascades.
- Precipitation Range: 25 to 41 cm (10 to 17 in). Rapid establishment 35 to 41 cm (15 to 17 in).
- Tolerances: Good drought, fair salt, poor high water table, moderately tolerant to close grazing.

Uses: Grazing. Awns may cause injury to livestock during seed development. Good forage prior to and after early summer.

PRAIRIE SANDREED
(*Calamovilfa longifolia* (Hook.) Scribn.)

Propagation/Reproduction:
- Natural: Season of growth begins in late spring. Flowers between July and September.
- Artificial Establishment: Fair ease of establishment. Prechill for 2 weeks to improve germination. May require irrigation. Stands develop slowly.
- Colonizing Ability: Vigorous rhizomes. Long-lived. Strongly competitive when established.
- Habit: Warm season sod former. Midgrass. Culms 60 to 160 cm (2 to 5 ft) tall. Attached to stout scaley, spreading rhizomes. Leaves rigid 30 cm (1 ft) or longer. Tapered. Coarse, fibrous root system.

Habitat:
- Soil: Best on sandy textures. Grows on loamy textures. Well-drained soils.
- Elevation: 600 to 1,800 m (2,000 to 6,000 ft).
- Distribution: Eastern Wyoming and Montana, western Dakotas and Nebraska.
- Precipitation Range: 25 to $>$ 50 cm (10 to 20 in).
- Tolerances: Fair to good drought, poor salt, poor high water table. Low shade and close grazing.

Uses: Grazing and erosion control. Dune stabilization. Noted variety is Goshen.

PUBESCENT WHEATGRASS (Stiffhair wheatgrass)
(*Agropyron trichophorum* (Link.) Richt.)

Propagation/Reproduction:
- Natural: Season of growth begins in early spring. Matures in mid to late summer.
- Artificial Establishment: Easily established from seed. Good growth rate. Strong seedling vigor. Good germination and growth rate.
- Colonizing Ability: Medium longevity. Spreads aggressively from seed and rhizomes. Strong competitor.
- Habit: Similar to intermediate wheatgrass (*A. intermedium*). Distinguishing difference is dense pubescence on spikes, spikelets, glumes, and lemmas. Cool season, sod former. 60 to 130 cm (2 to 4 ft) tall.

Habitat:
- Soil: All textures. Prefers loamy sand to loam.
- Elevation: 300 to 3,000 m (1,000 to 10,000 ft).
- Distribution: Western Great Plains to Sierra Nevadas.
- Precipitation Range: 25 to $>$ 50 cm (10 to $>$ 20 in). Best at 30 to 45 cm (12 to 18 in).
- Tolerances: Fair to good drought, fair salt, fair high water table and flooding. More drought, heat, and salt tolerant than intermediate wheatgrass.

Uses: Erosion control, grazing, wildlife. Not as palatable as intermediate wheatgrass. Varieties: Greenleaf, Luna, Mandan 759, Topar.

REED CANARYGRASS
(*Phalaris arundinacea* L.)

Propagation/Reproduction:
- Natural: Most growth during cool spring months. Growth period October through May.
- Artificial Establishment: Difficult to average ease of establishment. Propagate by seed or culm cutting or sprigging. Easy to handle.
- Colonizing Ability: Persistent, moderate seedling vigor, slow growth.
- Moderate rate of spread. Winter-hardy.
- Habit: Cool season, sod former. Tall grass. Grows in clumps up to 1 m across. Seed heads 5 to 20 cm (2 to 8 in) long.

Habitat:
- Soil: All soils. Prefers loamy to clayey textures.
- Distribution: North and Central Great Plains, Intermountain Basins, Oregon and Washington.
- Precipitation Range: $>$ 40 cm (16 in) reported.
- Tolerances: Fair drought, poor salt, very good high water table. Will not survive continuous close grazing. Tolerant of acidic conditions. Not tolerant of sodic conditions.

Uses: Native hay, pasture, silage, erosion control, grassed waterways, wildlife. Moderate palatability. Best used in drainages, i.e., moist conditions, but will survive on uplands.

Comments: Several varieties available.

SAND BLUESTEM
(*Andropogon hallii* Hack.)

Propagation/Reproduction:
Natural: Season of growth is April through October. Seed matures in October.
Artificial Establishment: Easy to establish by seed. Seed needs to be processed to use seed drills.
Colonizing Ability: Invades blow-out areas. Spreads by heavy creeping rhizomes. Good lateral spread.
Habit: Warm season, sod former. Tall grass.

Habitat:
Soil: Sand to loam textures. Prefers sandy conditions.
Elevation: Up to 1,312 m (4,300 ft) reported for New Mexico.
Distribution: Dakotas to Texas.
Precipitation Range: 35 to > 50 cm (14 to > 20 in).
Tolerances: Fair drought, poor salt, fair to high water table. Not tolerant of close grazing.

Uses: Grazing, erosion control on sandy soils. Palatable. Varieties are Elida, Garden, Goldstrike and Woodward. Important species for controlling erosion in sandy conditions.

SAND LOVEGRASS
(*Eragrostis trichodes* (Nutt.) Wood)

Propagation/Reproduction:
Natural: Season of growth is March through November. Seed ripens in September through October.
Artificial Establishment: Easily established by seed. Mechanical seed harvesting from native stands may be difficult due to presence of brushy plants.
Colonizing Ability: Readily reseeds. Short to medium longevity. May increase in size by tillering. Persistence decreases under heavy grazing. Volunteers aggressively.
Habit: Warm season, bunchgrass. Mid to tall grass. 1 to 2 m (3 to 6 ft) tall. Leaves up to 30 cm (12 in) long. Roots are vigorous, spreading, and deeply penetrating.

Habitat:
Soil: Sand to fine loamy textures. Prefers coarser textures. Calcareous soils. Well-drained soils only.
Distribution: Great Plains (southern portion of the north region)
Precipitation Range: 32 to > 50 cm (13 to > 20 in). Best at > 40 cm (16 in.).
Tolerances: Good drought, poor salt, poor high water table. Not tolerant of heavy, close grazing.

Uses: Grazing, stabilization of sandy soils. Very palatable and nutritious. Frequently suffers from overuse. Varieties in use: Bend, Mason, and Nebraska 27.

SAND DROPSEED
(*Sporobolus cryptandrus* (Torr.) A. Gray)

Propagation/Reproduction:
Natural: Season of growth is April through October. Seed matures September to October.
Artificial Establishment: Reports vary from difficult to easy. Moderate growth rate. Propagate by seed. Plant shallow. Seeds require scarification or dry storage. Protect seedlings.
Colonizing Ability: Prolific seed production. Invades disturbed areas. Increases on depleted range.
Habit: Warm season, bunchgrass. Midgrass. 60 to 90 cm (2 to 3 ft) tall. Leaves 10 to 30 cm (4 to 12 in) long. Roots are coarse, fibrous, and penetrating.

Habitat:
Soil: Sandy to clayey textures. Prefers coarse textures. Shallow calcareous soils.
Distribution: Central and southern Great Plains and Rocky Mountains. From southwestern deserts to eastern Washington.
Precipitation Range: 20 to > 50 cm (8 to 20 in). Best at 25 to 45 cm (10 to 18 in).
Tolerances: Good drought, fair salt, fair high water table. Not tolerant of shade. Not tolerant of heavy use.

Uses: Grazing on depleted ranges. Revegetation of disturbed lands. Fair palatability (decreases with age). Fair winter forage.

SANDBERG BLUEGRASS
(*Poa secunda* Presl.)

Propagation/Reproduction:
Natural: Growth begins in early spring before other native cool season grasses. Matures in early summer. Renews growth in fall.
Artificial Establishment: May be difficult to establish from seed. Seedling vigor is weak. Poor stands generally reported.
Colonizing Ability: Increases with grazing use on most rangelands. Poor seed production. Competitive when established.
Habit: Cool season, bunchgrass. Culms 20 to 40 cm (8 to 16 in) tall. Short, mostly basal leaves. Densely tufted. Shallow to deep, finely branched fibrous root system.

Habitat:
Soil: All textures. Dominant on shallow, rocky soils.
Elevation: < 2,100 m (7,000 ft).
Distribution: Western Dakotas to eastern Washington, Nevada, Utah, California, western Colorado.
Precipitation Range: > 25 cm (> 10 in).
Tolerances: Good drought, fair salt, poor on prolonged flooding. Moderate shade, good grazing.

Uses: Grazing, erosion control. Similar species is Canby bluegrass (*P. canbyi*), which is native, taller, longer leaved, later maturing, and more productive. Use adapted seed source.

SIDE-OATS GRAMA

(*Bouteloua curtipendula* (Michx.) Torr.)

Propagation/Reproduction:

Natural: Season of growth is April through October. Seed matures in August through October.

Artificial Establishment: Fair ease of establishment from seed. Seed should be cleaned prior to use of normal seed drills. No information on transplanting.

Colonizing Ability: Good persistence. Underground stems. Long-lived.

Habit: Warm season, bunchgrass. Sod former under heavy grazing. Midgrass. 60 cm to 1 m (2 to 3 ft) tall. Leaves 15 cm (6 in) long. Root system is well branched and fairly deep.

Habitat:

Soil: All soils. Prefers sandy to clay loams. Shallow and calcareous soils. Successful in rocky or gravelly soils.

Elevation: Up to 2,300 m (7,000 ft) reported.

Distribution: Great Plains, central and southern Rocky Mountains, Southern Plateaus.

Precipitation Range: 20 to 〉 50 cm (8 to 〉 20 in). Best at 〉 30 cm (12 in).

Tolerances: Fair to good, drought, poor to fair salt, fair high water table. Tolerant of low fertility.

Uses: Native hay, grazing, erosion control and wildlife. Varieties in use are numerous.

SLENDER WHEATGRASS

(*Agropyron trachycaulum* (Link) Malte)

Propagation/Reproduction:

Natural: Season of growth from September through June. Seed matures in July and August.

Artificial Establishment: Easy to establish. Propagated by seed. Seeds germinate quickly, are vigorous and fast growing. Some reports indicate transplanting success is good. Suggested for seed mixtures rather than as single species planting.

Colonizing Ability: Stand density decreases rapidly after 4th year. Short-lived. Fair persistence. Bunches enlarge by tillering.

Habit: Cool season, bunchgrass. Midgrass. Up to 1 m (3 ft). Leaves 9 to 32 cm (3 to 13 in) long.

Habitat:

Soil: All textures, prefers loamy to clayey textures.

Distribution: Northern and central Great Plains and Rocky Mountains. Columbia Basin Cascades and Sierra Nevadas, northern and central Intermountain Basins.

Precipitation Range: 32 to 〉 50 cm (13 to 〉 20 in).

Tolerances: Fair to good drought, fair to good salt, poor to fair high water table. Not tolerant to close grazing.

Uses: Native hay, grazing, produces quick cover for erosion control.

SMOOTH BROME

(*Bromus inermis* Leyss)

Propagation/Reproduction:

Natural: Season of growth begins in early spring. Matures in June or July. Vigorous growth in May and June. Good regrowth in early summer.

Artificial Establishment: Easily established from seed. Can transplant easily. Good growth rate. Strong seedling vigor.

Colonizing Ability: Moderate to long-lived. Spreads by rhizomes and seed. Good persistence.

Habit: Cool season, sod former. Culms 60 to 130 cm (2 to 4 ft) tall. Leafy base with brown, scaley rhizomes. Broad, smooth leaf blades. Dense, fibrous, surface roots and rhizomes. Moderately deep, extensive roots.

Habitat:

Soil: All textures. Prefers loamy. Weakly acid to weakly alkaline. Well drained.

Elevation: 1,500 to 3,300 m (5,000 to 11,000 ft); changes with latitude.

Distribution: All Western States.

Precipitation Range: 35 to 〉 50 cm (14 to 〉 20 in).

Tolerances: Fair drought, fair salt, fair to good high water table and flooding.

Uses: Pasture, irrigated hay, erosion control, wildlife plantings. Many varieties. Northern and southern type strains. Numerous species in this genus (both native and introduced) suitable for reclamation. Check with local agencies for adapted species and variety.

STREAMBANK WHEATGRASS

(*Agropyron riparium* Scribn. & Smith)

Propagation/Reproduction:

Natural: Season of growth and seed maturity similar to that for thickspike wheatgrass (*A. dasystachyum*).

Artificial Establishment: Easy to establish from seed. Quick germination, moderate seedling vigor.

Colonizing Ability: Good longevity. Rhizomatous.

Habit: Cool season, sod former. Midgrass. Similar in appearance to thickspike wheatgrass (*A. dasystachyum*).

Habitat:

Soil: All soil textures. Best on loamy textures. Sodic conditions.

Elevation: Reported at 1,070 m (3,500 ft) and up.

Distribution: Northern Great Plains and Rocky Mountains, Snake River Plain and Columbia Basin, Great Basin Intermontane, Cascades-Sierra Nevadas, Northern and central Intermountain Basins.

Precipitation Range: 12 to 40 cm (5 to 18 in).

Tolerances: Good drought, fair salt, fair high water table, moderate grazing.

Uses: Erosion control, wildlife. Airfield surfaces. Adapted to subalpine and droughty conditions. Often overlooked for droughty conditions because of name. Variety: Sodar.

SWITCHGRASS
(*Panicum virgatum* L.)

Propagation/Reproduction:

Natural: Season of growth is April through October. Seed matures in September or October.

Artificial Establishment: Average ease of establishment. Rhizomatous. Spread assumed to be good. Germination improved by storing for one year.

Colonizing Ability: Long-lived. Seedling growth is aggressive. Persistence not determined. High yields of seed.

Habit: Warm season, sod forming. 1 to 1.7 m (3 to 5 ft) tall. Leaves 15 to 45 cm (6 to 18 in) long. Heavy, vigorous roots and underground stems. Short, vigorous rhizomes.

Habitat:

Soil: Sandy to clayey textures. Best in loamy.

Distribution: Great Plains, Southern Plateaus.

Precipitation Range: > 40 cm (16 in).

Tolerances: Fair drought, fair salt, good high water table. Tolerates acid and low-fertility soils.

Uses: Important forage and pasture grass. Erosion control. Native hay. Typically found with bluestems. Many ecotypes for variety of conditions.

TALL FESCUE
(*Festuca arundinacea* Schreber)

Propagation/Reproduction:

Natural: Good early summer and late fall regrowth. Growth season and maturity ranges with latitude.

Artificial Establishment: Easily established from seed. Can be transplanted. High seedling vigor.

Colonizing Ability: Long-lived. Good rate of spread. Good persistence.

Habit: Cool season, bunchgrass. Mid to tall grass. 30 to > 100 cm (1 to 3 ft) tall. Densely tufted. Leaf blades stiff and flat. Large volume of deep, coarsely fibrous roots.

Habitat:

Soil: Sandy loam to clay textures. Wide range of pH. Needs summer moisture.

Distribution: All Western States except Dakotas.

Precipitation Range: > 45 cm (> 18 in).

Tolerances: Poor to fair drought, fair to good salt, good high water. Good grazing. Moderate shade.

Uses: Erosion control, grazing, and wildlife. Numerous species in this genus suitable for reclamation purposes. Check with local agencies for other adapted species. Both native and introduced.

TALL WHEATGRASS
(*Agropyron elongatum* (Host) Beauv.)

Propagation/Reproduction:

Natural: Season of growth begins in April or early May. Matures in late August or September. Regrowth good in summer and fall depending on moisture.

Artificial Establishment: Easily established from seed. Good growth rate. Prechilling hastens germination. Stands establish in 2 to 3 seasons. May require fertilization to maintain production.

Colonizing Ability: Medium longevity. Good seed production. Moderate to high seedling vigor.

Habit: Coarse, cool season, bunchgrass. Large tufted—up to 160 cm (5 ft) tall. Leaves 20 to 40 cm (8 to 16 in) long. Deep, productive root system.

Habitat:

Soil: Sandy to clayey textures. Best in loamy textures. Up to pH of 10.

Elevation: 150 to 2,600 m (500 to 7,500 ft).

Distribution: Dakotas, west to eastern Washington, western Colorado to Nevada, northern Arizona and New Mexico.

Precipitation Range: 32 to > 50 cm (13 to > 20 in).

Tolerances: Fair drought, very good salt, good high water table. Intolerant of heavy grazing. Fair shade.

Uses: Grazing, hay, silage. Upland birds. Soil stabilization. Standing winter feed. Varieties: Alkar, Jose, Largo, Orbit.

THICKSPIKE WHEATGRASS
(*Agropyron dasystachyum* (Hook) Scribn.)

Propagation/Reproduction:

Natural: Season of growth begins in spring. Seed usually matures in July. Good fall and fair summer regrowth.

Artificial Establishment: Fair ease of establishment from seed. Prechilling seed improves germination. Light irrigation on droughty sites.

Colonizing Ability: Long-lived. Fair seedling vigor. Spreads aggressively after fires remove shrubs. Slow spread otherwise.

Habit: Cool season, sod former. Single stem to small tufted. Up to 1 m (3 ft) tall. Widely spreading rhizomes. Dense, fibrous root systems.

Habitat:

Soil: Loamy sand to clay loam textures. Best on medium to coarse. Well drained.

Elevation: Sea level to 3,300 m (0 to 10,000 ft).

Distribution: From northern Arizona and New Mexico to eastern Washington. East through Dakotas, Wyoming, and Colorado.

Precipitation Range: 15 to > 50 cm (6 to > 20 in).

Tolerances: Good drought, fair salt, moderate of early spring flooding. Moderate shade and grazing.

Uses: Erosion control, soil stabilization, upland bird cover. Varieties: Critana.

TIMOTHY

(*Phleum pratense* L.)

Propagation/Reproduction:

Natural: Growth begins in early to late spring. Matures in early to late summer.

Artificial Establishment: Easily established from seed. High seedling vigor, good growth rate.

Colonizing Ability: Short to medium longevity, good rate of natural spread. Fair persistence.

Habit: Small tufted, cool season. Erect culms 60 to 115 cm (2 to 3.5 ft) tall. Leaf blades soft, flat, rough edged up to 30 cm (1 ft) long. Moderately shallow, fibrous root system.

Habitat:

Soil: All textures. Prefers finer textures.

Elevation: Sea level to subalpine. Dependent on moisture.

Distribution: Western United States (requires moisture).

Precipitation Range: $>$ 37 cm ($>$ 15 in)

Tolerances: Poor drought, fair salt, fair to good high water table. Not tolerant of heavy grazing.

Uses: Hay, pasture, erosion control. Similar native species is Alpine timothy (*P. alpinum*).

WESTERN WHEATGRASS

(*Agropyron smithii* Rydb.)

Propagation/Reproduction:

Natural: Season of growth is September through June. Seed matures July through August.

Artificial Establishment: Average ease of establishment. Slow germination. Rhizomatous. Seed germination improved by 6 months to 1 year of dry storage. Can be transplanted.

Colonizing Ability: Spreads rapidly. Very competitive. Very good persistence. Very hardy.

Habit: Cool season, sod former. Midgrass. 60 to 100 cm (2 to 3 ft) tall. Leaves 20 to 30 cm (8 to 12 in) long. Leaf blades stiff and erect. Entire plant usually covered with a grayish bloom. Root systems profuse and dense.

Habitat:

Soil: Prefers loamy to clayey textures. Grows in sandy soils.

Elevation: Assumed to be wide.

Distribution: Western United States (southern Great Plains excluded).

Precipitation Range: 12 to $>$ 50 cm (5 to $>$ 20 in).

Tolerances: Good drought, very good salt, good high water table. Tolerant of siltation. Moderately tolerant of close grazing.

Uses: Grazing (excellent winter forage) native hay. Erosion control, wildlife. Excellent for variety of conditions. Many varieties, e.g., Arriba, Barton, Rosana.

Comments: Generally adapted to short and midgrass prairies, aspen, sagebrush foothill, Juniper-pinyon, and saline alkaline bottomlands.

ALFALFA
(*Medicago sativa* L.)

Propagation/Reproduction:

Natural: Growth season begins in early spring and continues to fall. Flowers from early to late summer.

Artificial Establishment: Easily established from seed. Inoculate seed. Can transplant.

Colonizing Ability: Good seedling vigor. May be outcompeted by weeds until established. Some rhizomatous varieties available.

Habit: Cool and warm season, legume. Numerous erect stems 60 cm to 1 m (2 to 3 ft) tall. Small leaves. Stout, deep-rooted plants. Taproots may be up to 10 m (30 ft) long.

Habitat:

Soil: Sandy to loamy textures. Well drained. Neutral to slightly alkaline calcareous.

Elevation: Below sea level to 2,400 m (8,000 ft).

Distribution: All Western States.

Precipitation Range: 30 to > 50 cm (12 to 20 in).

Tolerances: Fair drought, fair salt, poor high water table.

Uses: Grazing in mixed pastures, hay, wildlife, erosion control. Can cause bloat. Many varieties available for different conditions. Highly palatable. Considerable variation in winter hardiness.

AMERICAN VETCH
(*Vicia americana* Muhl. ex Willd.)

Propagation/Reproduction:

Natural: Season of growth begins in early spring. Flowers from May to August. Seeds mature 1 month later.

Artificial Establishment: Fair ease of establishment from seed. Fair growth rate. Good transplanting capabilities.

Colonizing Ability: Weak seedling vigor and rate of spread. Persistence is good once established and if managed correctly.

Habit: Cool season, legume. Stems angled, ascending or climbing 15 to 75 cm (0.5 to 2.5 ft) tall. Leaves pinnate 8 to 12 leaflets. Purplish flowers. Seed pods 2.5 to 3.7 cm (1 to 1.5 in) long. Moderately deep roots. Branched taproots and spreading rhizomes.

Habitat:

Soil: Loamy sand to clay loam textures. Prefers deep loams. Slightly acid to moderately alkaline and saline.

Distribution: All Western States. Southwest deserts excluded.

Precipitation Range: 35 to 50 cm (14 to > 20 in).

Tolerances: Good drought, good salt, good shade. Depends on ecotype. Decreaser.

Uses: Grazing, wildlife, erosion control. Palatable. Use adapted seed source. Polymorphic species with many ecotypes.

ARROWLEAF BALSAMROOT
(*Balsamorhiza sagittata* (Pursh) Nutt.)

Propagation/Reproduction:

Natural: Season of growth in early spring to early summer. Seed matures in late June to early August. Little summer and fall regrowth depending on moisture.

Artificial Establishment: Fair ease of establishment. Slow growth rate. Seeds germinate over 8-week period. Moist, prechilling at 0° to 5°C for 12 weeks improves germination.

Colonizing Ability: Good persistence once established. Spreads by seed. Good competitiveness once established.

Habit: Cool season, herbaceous. 30 to 60 cm (1 to 2 ft) tall. Leaves mostly basal, long stalks, 30 cm (1 ft) long or longer. Silvery-grey to white wooly pubescent. Yellow flowers 2.5 to 5 cm (1 to 2 in) long. Achene type seeds. Thick, moderately deep taproot.

Habitat:

Soil: Silty and loamy textures. Well drained. Slightly acid to moderately alkaline. Slightly saline.

Elevation: 300 to 2,700 m (1,000 to 9,000 ft).

Distribution: Intermountain West. Western Coastal States.

Precipitation Range: 25 to > 50 cm (10 to > 20 in).

Tolerances: Good drought, fair salt. Poor high water table. Good grazing and fair shade.

Uses: Restoring big game range, grazing, revegetation. Use local seed source. Flowers add color and are esthetically pleasing.

BIRDSFOOT TREFOIL (Birdsfoot deervetch)
(*Lotus corniculatus* L.)

Propagation/Reproduction:
- Natural: Not determined
- Artificial Establishment: Fair ease of establishment from seed. Transplanting ease not determined. Inoculate seed.
- Colonizing Ability: Seems to spread well from seed.
- Habit: Warm season, legume. 50 to 100 cm (20 to 40 in) tall. Upright spreading stems. Alternate leaves in groups of three with two broad leaflets at the base of each leaf branch. Flowers are yellow to deep orange, tinged with red, in clusters of 4 to 8. Slender seed pods 2.5 cm (1 in) long. Deep rooted, branching laterals.

Habitat:
- Soil: Sandy loam to clay loam textures. Acid tolerant. Wet or poorly drained.
- Distribution: Northern and Central Great Plains, Rocky Mountains, Great Basin Intermontane, Columbia Basin, Snake River Plain, Southern Plateaus.
- Precipitation Range: 40 to > 50 cm (16 to > 20 in).
- Tolerances: Poor drought, fair salt, fair high water table. Low shade.

Uses: Grazing, wildlife. Hay. Erosion control. Nutritious and palatable. Many varieties. Use adapted varieties. Does not cause bloat.

CICER MILKVETCH (Chick-pea)
(*Astragalus cicer* L.)

Propagation/Reproduction:
- Natural: Season of growth late spring to early fall. Regrowth in fall with moisture. Seeds mature from August to October.
- Artificial Establishment: Fair to difficult ease of establishment. Direct seeding on favorable sites. Transplant is more successful on difficult sites. Seeds require scarification. Slow rate of establishment. Varying results in revegetation trials.
- Colonizing Ability: Vigorous creeping rhizomes. Long-lived. Fair persistence. Produces large quantities of seed.
- Habit: Legume, medium height. Yellow flowers. Usually > 1 m (3 ft) tall. Leaves 10 to 20 cm (4 to 8 in) long. Odd pinnate, with 21 to 27 light green leaflets about 2.5 to 5 cm (1 to 2 in) long. Short tap root. Spreads up to 10 ft. Black pods at maturity.

Habitat:
- Soil: Survives on all soil textures. Prefers loamy or clayey textures. Weakly acid to moderately alkaline.
- Elevation: 610 to 2,135 m (2,000 to 7,000 ft).
- Distribution: All Western States.
- Precipitation Range: 35 to > 50 cm (14 to > 20 in) optimum, 46 to 90 cm (18 to 35 in).
- Tolerances: Fair drought, fair salt, fair high water.

Uses: Grazing, mixed hay, wildlife. Nitrogen-fixing. Erosion control. Varieties: Cicar, Lutana, Monarch. Good cover from spring through fall. Poor in winter. Other species in this genus may be used in reclamation. Check with local agencies for adapted varieties.

CROWNVETCH
(*Coronilla varia* L.)

Propagation/Reproduction:

Natural: Season of growth early spring to early fall. Flowers from June to August.

Artificial Establishment: Good ease of establishment from seed. Transplants well. Fair seedling vigor. Inoculate with specific bacteria.

Colonizing Ability: Rhizomatous. Moderately fast germination. Very competitive once established. May form monoculture. Grazing or mowing thins stands. Good persistence. Spreads slowly.

Habit: Cool season, leguminous. 30 to 130 cm (1 to 4 ft) tall. Creeping stems 60 cm to 2 m (2 to 6 ft) long. Alternate leaves. 9 to 25 leaflets. Deep tap root; heavy, branched root crown. Pinkish-lavender to white flowers.

Habitat:

Soil: Loamy textures. Calcareous. Well drained. pH > 5.0.

Distribution: Northern Great Plains, Central Rocky Mountains, Great Basin Intermontane

Precipitation Range: 35 to > 50 cm (14 to > 20 in) optimum, above 45 cm (18 in).

Tolerances: Weakly moderate drought, poor to fair salt, very poor to high water table, moderate shade, moderate to grazing.

Uses: Ground cover, erosion control. Temporary grazing. Value as forage questionable. Reports vary for palatability. Use adapted varieties. Requires adequate moisture.

GOOSEBERRY GLOBEMALLOW
(*Sphaeralcea grossulariaefola* (H.& A.) Rydb.)

Propagation/Reproduction:

Natural: Season of growth begins in early spring. Flowers in May or July. Seed matures in June to August. Greens-up again in fall.

Artificial Establishment: Fair ease of establishment. Seeds germinate moderately rapid. Scarification of seed improves germination. Protect from grazing until established.

Colonizing Ability: Good seedling vigor. Spreads by seed, especially in disturbed areas. Weakly moderate in competitiveness.

Habit: Cool season, erect. 30 to 75 cm (1 to 2 ½ ft) tall. Grows in loose tufts. Leaves egg shaped in outline, palmately three-lobed. Flowers on short branches. Red petals, central staminal tube. Branched taproot with several surface roots.

Habitat:

Soil: Sandy to clay loam textures. Shallow and gravelly conditions.

Distribution: Great Basin. New Mexico, Arizona north to Washington.

Precipitation Range: Prefers 20 cm to 30 cm (8 to 12 in).

Tolerances: Good drought, moderately saline, poor sodic. Good shade. Winter-hardy but may not survive dry, snow-free winters of Great Plains. Moderately tolerant of grazing.

Uses: Erosion control, grazing, range and mine revegetation.

ILLINOIS BUNDLEFLOWER (pickle weed)
(*Desmanthus illinoensis* (Michx.) MacM.)

Propagation/Reproduction:
Natural: Season of growth is late spring to fall. Flowers from late June through September. Seed matures about 1 month later.
Artificial Establishment: Easily established from seed. Transplants well. Scarification improves germination. Inoculate with specific Rhizobia.
Colonizing Ability: Spreads from seed. Seems to be competitive. Seedling vigor is very good. May produce seed in first season.
Habit: Warm season, leguminous. 60 cm to 120 cm (2 to 4 ft) tall. Alternate leaves 10 cm (4 in) long. 6 to 15 pairs of pinnal, each with 20 to 30 pairs of small leaflets. White flowers. Deep, woody roots. Flat scythe shaped seed pods 2.5 to 4 cm (1 to 1.5 in) long.

Habitat:
Soil: Sandy loam to light clay textures. Moderately acid to slightly alkaline.
Distribution: Northern and Central Great Plains
Precipitation Range: 38 to 〉 50 cm (15 to 〉 20 in).
Tolerances: Good drought, salt tolerance may be fair, good for high water table or flooding. Not tolerant of close grazing. Winter-hardy.

Uses: Grazing and wildlife. Erosion control. Decreases under heavy use. Use adapted species. Usually found in moist depressions but fairly common in open communities without full competition.

LEWIS FLAX (Blue flax)
(*Linum lewisii* Pursh)

Propagation/Reproduction:
Natural: Growth begins in spring. Flowers between May and September. Matures 4 to 6 weeks after flowering.
Artificial Establishment: Easily established from seed. Easily transplanted. Fair growth rate. Good seedling vigor for forb.
Colonizing Ability: Excellent natural spread by seed. Good persistence.
Habit: Cool season, herbaceous, forb. Stems slender, erect or drooping. Up to 1 m (3 ft) tall. Several showy flowers with five blue petals up to 2.5 cm (1 in) long. Deep, woody taproot.

Habitat:
Soil: Coarse textures. Well drained.
Elevation: Prairie to alpine.
Distribution: All Western States.
Precipitation Range: 25 to 〉 50 cm (10 to 〉 20 in).
Tolerances: Good drought, fair salt, poor high water table. Moderate grazing and shade.

Uses: Wildlife, grazing. Good palatability for big game. Esthetics.

MAXIMILLIAN SUNFLOWER
(*Helianthus maximiliani* Schrad.)

Propagation/Reproduction:
Natural: Season of growth is April through October, depending on moisture. Flowers from July to October.
Artificial Establishment: Easy to establish from seed. Transplant in early spring. Cuttings root in greenhouse. Seeds may be dormant.
Colonizing Ability: Good seedling vigor. Bunches from short rhizomes. Aggressive spread and good persistence under light use.
Habit: Warm season, bunching. 1 to 2 m (3 to 6 ft) tall. Leaves 10 to 15 cm (4 to 6 in) long. Typical sunflower shaped heads. Bright yellow. Short rhizomes.

Habitat:
Soil: Fine sands to light clays. Prefers loam textures. Slightly acid to slightly alkaline.
Elevation: Up to 2,000 meters (6,000 ft).
Distribution: Great Plains.
Precipitation Range: 35 to 〉 50 cm (14 to 〉 20 in).
Tolerances: Fair drought, fair saline, moderate high water table. Fair shade.

Uses: Grazing, wildlife, revegetation. Species decreases under heavy grazing. Use adapted varieties. Noted varieties: prairie gold, Aztec. Numerous species in this genus. Check with local agencies for adapted species.

NORTHERN SWEETVETCH
(*Hedysarum boreale* Nutt.)

Propagation/Reproduction:
Natural: Season of growth begins in early or midspring. Flowers in May and June. Seed matures in July and August.
Artificial Establishment: Easily established from seed. Easily transplanted. Germination improved by damp prechilling or scarification.
Colonizing Ability: Propagates by seed and sometimes rhizomatous. Moderate competitiveness for a forb. Good persistence once established and under reduced competition.
Habit: Cool season, legume. Single to several stems from woody crown. 30 to 60 cm (1 to 2 ft) tall. Alternate leaves with 11 to 31 elliptic leaflets. White, pink, or purple flowers. Deep taproots and several laterals.

Habitat:
Soil: Sandy to clayey textures. Prefers loamy, well-drained soils. Slightly acid to neutral soils.
Elevation: 1,200 to 2,600 m (4,000 to 8,000 ft).
Distribution: Intermountain Region. Western edge of the Great Plains.
Precipitation Range: 25 to 〉 50 cm (10 to 〉 20 in). Prefers 〉 37 cm (15 in).
Tolerances: Good drought, poor salt, poor high water table. Fair to moderate grazing.

Uses: Grazing, wildlife. Improves soil fertility.

PURPLE PRAIRIE CLOVER
(*Petalostemon purpureum* (Vent.) Rydb.)

Propagation/Reproduction:

Natural: Season of growth begins mid to late spring. Flowers from late May to July or later. Seeds mature July and August or later (elevation differences).

Artificial Establishment: Fair ease of establishment from seed. Poor transplanting. Dry-chill at 40°C over winter or dry store for 1 year. Scarification also improves germination. Inoculate seed.

Colonizing Ability: Medium competitiveness. Spreads by seed. Seedling vigor medium.

Habit: Warm season, herbaceous legume. Several branched, streaked stems ascending or erect. 30 cm to 1 m (1 to 3 ft) tall. Stalked leaves with 3 to 7 leaflets. Dense, oblong terminal spike, 1.2 to 5 cm (½ to 2 in) long, composed of small rose or purple flowers. Woody taproot and several surficial branches.

Habitat:

Soil: Loamy sand to clay loam textures. Well drained. Moderately alkaline, calcareous.

Elevation: Up to 2,100 m (7,000 ft).

Distribution: Great Plains.

Precipitation Range: 30 to $>$ 50 cm (12 to $>$ 20 in).

Tolerances: Moderate drought, fair salt, poor high water table. Moderate grazing.

Uses: Range vegetation, erosion control. Some wildlife. Fair palatability to sheep, less for cattle. Use adapted seed source. White prairie clover (*P. candidum*) is similar. Has white flowers, often more decumbent spreading form. 5 to 7 leaflets. Requires less precipitation and tolerant of coarser, drier, and disturbed soils. Distributions of these species overlap.

ROCKY MOUNTAIN PENSTEMON
(*Penstemon strictus* Benth.)

Propagation/Reproduction:

Natural: Season of growth begins in early spring. Flowers from late May through June. Matures in July or later.

Artificial Establishment: Fair ease of establishment from seed. May transplant well. Seed germinates in about 14 days under favorable conditions. May require weed control until established.

Colonizing Ability: Spreads by seed. Decumbent stems grow roots when in contact with moist soil. Seedling vigor good for forb. Persistent once established. May be outcompeted by grasses.

Habit: Cool season, herbaceous. Several smooth, strictly erect stems. 30 to 75 cm (1 to 2.5 ft) tall. Basal leaves from rosette-like tufts. Numerous ascending flowers on one-sided raceme. Flowers deep blue or purple at throat, lighter blue in tube. Few large and many fine, shallow roots.

Habitat:

Soil: Sandy loam textures. Rocky. Slightly acidic and alkaline.

Elevation: 1,800 to 3,300 m (6,000 to 11,000 ft).

Distribution: Northeastern Arizona, New Mexico, Western Colorado, Utah, southern Wyoming.

Precipitation Range: 18 to $>$ 50 cm (13 to $>$ 20 in).

Tolerances: Fair drought, salt and high water table not determined.

Uses: Forage when mature for wildlife and livestock. Esthetics. Use adapted seed source. Many ecotypes. The Penstemon genus contains numerous species that may be useful in reclamation. Check with local agencies for suitable species and varieties.

SAINFOIN
(*Onobrychis viciaefolia* Scop.)

Propagation/Reproduction:
- Natural: Growth begins in spring (before alfalfa) and continues through summer with moisture.
- Artificial Establishment: Easily established from seed. Good seeding vigor. Best performance under irrigation. May require fertilization.
- Colonizing Ability: Moderately strong competitor. Short-lived (5 years). May be a decreaser on rangelands.
- Habit: Cool season, leguminous forb. 30 to 100 cm (1 to 3 ft) tall. Semi-erect stems. Numerous pink to purple pea-like flowers. Deep main taproot with several large and many fine laterals.

Habitat:
- Soil: Sandy to silty textures. Well drained. Calcareous.
- Distribution: East of Sierra Nevada-Cascades to eastern Montana, Wyoming, Utah, Nevada, and Colorado.
- Precipitation Range: 〉 32 cm (〉 13 in).
- Tolerances: Moderate drought, good salt, poor high water table. Moderate grazing, poor shade.

Uses: Pasture, grazing, hay, wildlife, erosion control. Varieties: Eski, Remont, Melrose.

SCARLET GLOBEMALLOW
(*Sphaeralcea coccinea*)

Propagation/Reproduction:
- Natural: Season of growth begins in early spring. Flowers from May to July. Seed matures in late July.
- Artificial Establishment: Good ease of establishment. Germination is good. Requires little scarification.
- Colonizing Ability: Spreads by rhizomes and seed. Commonly found on disturbed soils.
- Habit: Cool season, forb. 8 to 25 cm (3.0 to 10 in) tall. 6 to 12 cm (2.5 to 4.8 in) spread. Bright red-orange flowers. Deep, spreading root system.

Habitat:
- Soil: Sandy to clayey loam textures. Prefers clayey soils.
- Elevation: 900 to 2,100 m (3,000 to 7,000 ft).
- Distribution: Native to Great Plains
- Precipitation Range: No data. Probably similar to gooseberry leaf globemallow.
- Tolerances: Good drought, fair salt.

Uses: Reclamation, not highly sought after as forage.

SMALL BURNET
(*Sanguisorba minor* Scop.)

Propagation/Reproduction:
- Natural: Growth resumes in early spring. Flowers in early summer. Seed matures in late summer.
- Artificial Establishment: Easily established from seed. Fairly easy to transplant. Control weeds. Stands develop slowly.
- Colonizing Ability: Good propagation by seed. Fair rate of spread. Fair persistence.
- Habit: Cool season, herbaceous, evergreen. 15 to 60 cm (0.5 to 2 ft) tall. Tufted with many ascending stems. Flowers unisexual or bisexual borne in dense head or terminal spike. Taproot and short root stock.

Habitat:
- Soil: Sandy loam to clayey textures. Prefers loamy. Well drained moderately alkaline.
- Distribution: Northern New Mexico and Arizona west to Sierra Nevadas. North to Idaho and Montana.
- Precipitation Range: 〉 30 cm (〉 12 in).
- Tolerances: Good drought, moderate salt, poor high water table. Moderate grazing, fair shade. Winter-hardy.

Uses: Revegetating mined lands, rangelands, and big game range. Variety: Delar.

WESTERN YARROW
(*Achillea millefolium lanulosa* (Nutt.) Piper)

Propagation/Reproduction:
- Natural: Growth begins in early spring. Flowers in late spring through summer. Matures in summer and fall.
- Artificial Establishment: Easily established from seed. Can transplant. Good seedling vigor.
- Colonizing Ability: Persists by seed and rhizomes. Strongly competitive when established. Weedy. Invades rapidly.
- Habit: Cool season, herbaceous, forb. 30 to 100 cm (1 to 3 ft) tall. May be shorter. Small composite flower heads. White. Shallow, fibrous roots and extensive slender rhizomes.

Habitat:
- Soil: Loamy textures. Moist.
- Elevation: Prairie to alpine
- Distribution: Western States.
- Precipitation Range: 〉 45 cm (18 in); also survives at lower ranges.
- Tolerances: Poor to fair drought, fair salt, good flooding and high water table. Good grazing and shade.

Uses: Mostly wildlife, some grazing. Soil stabilization. Use adapted seed source. Similar species is common yarrow (*A. millefolium*). Introduced. Many authors consider species the same.

WHITE CLOVER
(*Trifolium repens* L.)

Propagation/Reproduction:

Natural: Season of growth from early to mid spring. Flowers in May to July. Seeds mature 3 to 4 weeks later. Abundant regrowth in summer with less in fall.

Artificial Establishment: Fair ease of establishment. Inoculate before seeding. Control weeds and grasses.

Colonizing Ability: Fair in seedling vigor. Good stands need 2 to 3 years to establish. Grasses will outcompete this species. Spreads by seed and stolons.

Habit: Prostrate growing legume. Creeping stems up to 37 cm (15 in) long. Polymorphic species many intermediate types. Shallow rooted. Leaves vary widely in size and shape. Flower heads composed of 20 to 40 or more individual white to pinkish white florets on long stalks.

Habitat:

Soil: Clay loam to silt loam textures. Slightly acid to slightly alkaline.

Elevation: Sea level to subalpine.

Distribution: All Western States.

Precipitation Range: 35 to $>$ 50 cm (14 to $>$ 20 in).

Tolerances: Moderate drought, poor salinity, poor high water table.

Uses: Pasture, hay, grazing, erosion control, wildlife. Usually seeded in grass mixes. Turf and lawn uses. Several varieties available. Use adapted sources. Numerous species in this genus have similar traits. Check with local agencies for adapted species.

YELLOW SWEETCLOVER
(*Melilotus officinalis* (L.) Lam.)

Propagation/Reproduction:

Natural: Season of growth begins in early spring. Flowers in late spring or early summer. Good regrowth before flowering. None when mature.

Artificial Establishment: Easily established from seed. Fast growth rate. Good germination. Scarify seeds to improve germination. Inoculate. May require phosphorous fertilization.

Colonizing Ability: Very good persistence. Spreads by seed. Very strong competitor as seedling and when mature.

Habit: Cool season, legume. 60 cm to 2 m (2 to 6 ft) tall by 2nd season. Leaves trifoliate, dentate-margined. Small yellow flowers. Small one-seeded pods. Large taproot.

Habitat:

Soil: Sandy loam to clay loam textures. Strongly alkaline to slightly acid.

Distribution: Western States.

Precipitation Range: 25 to $>$ 50 cm (10 to $>$ 20 in).

Tolerances: Good drought, fair to good salt, poor to fair high water table. Good grazing, moderate shade.

Uses: Grazing, hay, silage, temporary pasture, wildlife. Good quick cover for erosion control. Green manure crop. Noted varieties: Cumino, Goldtop, Madrid. Yukon white sweetclover (*M. alba*) has similar characteristics.

ANTELOPE BITTERBRUSH
(*Purshia tridentata* (Pursh) DC.)

Propagation/Reproduction:
Natural: Flowers in April to June. Seed ripens in July to August.
Artificial Establishment: Good establishment by direct seeding with excellent germination rate and fair initial seedling growth rate. Seed production is excellent and seeds are easily handled. Rates of 0.5 to 3 lb/acre. Seed in late fall or early winter for natural stratification. Easily transplanted.
Colonizing Ability: Persistence is good but natural spread is poor. Good competitive ability. Generally compatible with grass and forbs.
Habit: Evergreen to late deciduous, small- to medium-sized shrub, 0.6 to 3.1 m (2 to 10 ft) tall. Fibrous root system with variable depth. Capable of nitrogen fixation.

Habitat:
Soil: Basic or acidic, well-drained, sandy to clayey soils. Does best on coarse soils.
Elevation: Sea level to 2,745 m (9,000 ft).
Distribution: New Mexico to California and north to British Columbia. Prevalent in Intermountain West.
Precipitation Range: 25 to 64 cm (10 to 25 in).
Tolerances: Good drought tolerance and fair salt tolerance. Grazing resistant. Moderately shade tolerant. Intolerant of flooding or high water table. Susceptible to fire except a sprouting ecotype.

Uses: Highly palatable browse for livestock and big game. Protection and food for small mammals and birds. Stoloniferous characteristic provides good soil-erosion control.

APACHE-PLUME
(*Fallugia paradoxa* (D. Don) Endl.)

Propagation/Reproduction:
Natural: Flowers in the summer and seed matures in early spring.
Artificial Establishment: Seeds germinate readily without scarification, but only fair establishment. Good seedling growth rate and drought resistance. Seed in fall or spring. Also propagated vegetatively but with difficulty.
Colonizing Ability: Often a pioneer plant on disturbed sites and raw slopes; prefers full sunlight. Weak competitive ability. Compatible with associates. Good ability to spread by seed and vegetatively.
Habit: Cool season, semievergreen, spreading with a range in height from 1 to 2 m (3 to 6 ft) and spread from 1 to 3 m (3 to 10 ft); shallow, spreading, fibrous root system.

Habitat:
Soil: Neutral to moderately basic, well drained, medium to coarse-textured soils.
Elevation: 600 to 1,500 m (2,000 to 5,000 ft).
Distribution: West Texas through New Mexico and Arizona. On dry arroyos, alluvial plains, and gravelly or rocky slopes. Common on Juniper-pinyon sites.
Tolerances: Fair salt and drought tolerance.

Uses: Good winter browse for sheep and big game; good for erosion control.

BIG SAGEBRUSH
(*Artemisia tridentata* Nutt.)

Propagation/Reproduction:

Natural: Flowers from July to October and seeds mature from October to December.

Artificial Establishment: Good establishment by direct seeding with excellent growth rate. Also may be propagated by stem cutting. Can be transplanted. Usually seeded in the fall but spring seeding possible.

Colonizing Ability: Good competitor with excellent persistence; long-lived. Good compatibility with associates. Good ability to spread naturally.

Habit: Ranges in height from 0.5 to 3 m (1.5 to 9 ft) with a spread ranging from 0.3 to 1.5 m (1 to 5 ft). Root system is deep and extensive. Recognized subspecies are: *A. tridentata vaseyana*, *A. tridentata wyomingensis*, and *A. tridentata tridentata*. Each have variable forms, palatabilities, and stress tolerances.

Habitat:

Soil: Well-drained, acidic and basic, medium to clayey soils. Prefers deep, fertile alluvial soils.

Elevation: 500 to 3,000 m (1,650 to 10,000 ft).

Distribution: New Mexico and Arizona to Nebraska and California. Most widespread shrub of Western North America.

Precipitation Range: 20 to 43 cm (7.5 to 17 in).

Tolerances: Good drought and fair salt tolerance. Intolerant of flooding.

Uses: Soil stabilizer on disturbed, exposed sites. Winter browse for wildlife and livestock, often of high protein content; aromatic oils may reduce its digestibility. Very important plant for reclamation work.

Comments: Less palatable ecotypes can be used for erosion control.

BLACK GREASEWOOD
(*Sarcobatus vermiculatus* (Hook.) Torr.)

Propagation/Reproduction:

Natural: Flowers in midsummer and seeds mature by early fall.

Artificial Establishment: Fair propagation by seed with good rate of germination. Fair seed production and ease of handling. Stem cuttings have not shown good success.

Colonizing Ability: Good persistence but slow rate of natural spread. Will form pure stands on saline areas. Established naturally on disturbed sites in its range.

Habit: Warm season, deciduous, erect or spreading, spiny shrub, 1 to 3 m (3 to 10 ft) tall with an equal spread. Deep taproot and/or shallow root system, depending on soil moisture.

Habitat:

Soil: Saline-alkaline clayey soils with high water table or seasonal flooding.

Elevation: 900 to 2,100 m (3,000 to 7,000 ft).

Distribution: West Texas to Arizona and north to Canada.

Precipitation Range: No data.

Tolerances: Excellent salt and good drought tolerance. Tolerant of flooding. Excellent grazing tolerance. Tolerant of sodium sites.

Uses: Important winter browse for livestock and wildlife. May be limited due to oxalate content. Good potential on mined soils for control of mass slippage and erosion.

BLACK SAGEBRUSH
(*Artemisia arbuscula nova* (A. Nels.) Cronq.)

Propagation/Reproduction:
- Natural: Flowers in September and seed matures in October.
- Artificial Establishment: Good establishment by seeding with fair seedling growth rate. Seed in late fall or winter. For average site, seed 0.5 to 1.016 lb/acre. Also can be propagated by stem cutting or by transplants.
- Colonizing Ability: Fair competitor but weak shade tolerance. Fair compatibility with most associated species. Excellent rate of natural spread.
- Habit: Semi-evergreen, low 10 to 40 cm (4 to 18 in) spreading 30 to 60 cm (1 to 2 ft) shrub; deep and extensively branched generalized root system.

Habitat:
- Soil: Neutral or slightly basic, well drained, shallow, medium-textured soils.
- Elevation: 1,200 to 2,400 m (4,000 to 8,000 ft).
- Distribution: Intermountain West and vicinity. Generally on foothills and rocky ridges and other exposed sites.
- Precipitation Range: 15 to 50 cm (6 to 20 in).
- Tolerances: Good drought tolerance but poor tolerance of salt or wet sites; fire intolerant; poor grazing tolerance.

Uses: Winter browse for sheep, deer, and antelope. Good for soil stabilization.

CATCLAW ACACIA
(*Acacia greggii* A. Gray)

Propagation/Reproduction:
- Natural: Flowers in May and June and seed pods mature from July to September.
- Artificial Establishment: Poor establishment by direct seeding; requires seed inoculation on mine tailings. More easily established by transplants.
- Colonizing Ability: Good ability to spread by seed and vegetatively.
- Habit: Warm season, deciduous, much branched, thicket forming, thorny, shrub or small tree.

Habitat:
- Soil: Shallow calcareous sites. Dry sandy or gravelly soils.
- Elevation: 305 to 1,370 m (1,000 to 4,500 ft).
- Distribution: West Texas through southern New Mexico and Arizona. Along dry washes and ravines, arid mesas, and canyon slopes.
- Precipitation Range: 18 to 43 cm (7 to 17 in).
- Tolerances: Strongly drought and grazing tolerant.

Uses: Low maintenance landscaping. Habitat for wildlife. Often the only browse available. When herbaceous forage is available its palatability is poor. Firewood. Honey plant.

CHOKECHERRY
(*Prunus virginiana* L.)

Propagation/Reproduction:
- Natural: Flowers during April through June and seed matures July through September. Reproduces naturally by seed.
- Artificial Establishment: Direct seeding in fall does not require stratification. Spring seeding. Surface germination. Only fair germination and seedling vigor expected on poor sites.
- Colonizing Ability: Sprouts readily from rhizomatous roots to form thickets. Prefers open sites. Competes well with grasses and forbs.
- Habit: Cool season, deciduous, large shrub or small tree. Height of 1.5 to 9 m (5 to 30 ft). Extensive, shallow, rhizomatous roots.

Habitat:
- Soil: Moist but well-drained sites and deep silty to sandy soils of good fertility. Moderately acid to moderately basic soils.
- Elevation: 1,370 to 2,440 m (4,500 to 8,000 ft).
- Distribution: Most of the cooler regions of Western United States. Widely distributed in Northern United States. Hillsides, canyons, and roadsides.
- Precipitation Range: 30 to 75 cm (12 to $>$ 30 in). Mesic, mountain areas.
- Tolerances: Intolerant of dense clay sites with poor drainage. Fair drought tolerance but less vigorous. Tolerant of moderate shade but prefers open sites. Moderately tolerant of grazing.

Uses: Erosion control. Toxic to livestock (hydrocyanic or prussic acid), but fair browse for wildlife. Probably best for reestablishing woody draws.

CREOSOTEBUSH
(*Larrea divaricata* Cav.)

Propagation/Reproduction:
- Natural: Flowers and sheds seeds throughout the year if sufficient moisture available.
- Artificial Establishment: Easily propagated by direct seeding; also by container stock.
- Colonizing Ability: Can form pure stands.
- Habit: Evergreen, strong scented, woody shrub

Habitat:
- Soil: Deep, well-drained sandy soil.
- Elevation: Sea level to 1,500 m (5,000 ft).
- Distribution: New Mexico, Arizona, and southern Utah Mojave Desert.
- Precipitation Range: 5 to 18 cm (2 to 7 in).
- Tolerances: Good drought tolerance. Poor shade tolerance. Not cold tolerant.

Uses: Unpalatable to livestock. Good potential for soil stabilization where herbivores may otherwise limit seeding establishment. Cover for wildlife.

CUNEATE SALTBUSH
(*Atriplex cuneata* A. Nels.)

Propagation/Reproduction:
- Natural: Flowers from April to July and seed matures mid-July to September.
- Artificial Establishment: Fair ability to be established by seed with a fair initial seedling growth rate and good seedling tolerance of droughty conditions. More easily propagated by transplant.
- Colonizing Ability: Good rate of natural spread but rarely forming dense stands.
- Habit: Evergreen, well branched, prostrate to slightly erect. Low shrub, 15 to 30 cm (6 to 12 in) tall with spread twice its height. Root system is spreading and deep.

Habitat:
- Soil: Highly alkaline clayey to coarse textured soils.
- Elevation: 1,220 to 2,130 m (4,000 to 7,000 ft).
- Distribution: Northern New Mexico, eastern Utah and southwestern Colorado.
- Precipitation Range: 15 to 25 cm (6 to 10 in).
- Tolerances: Excellent drought and salt tolerance.

Uses: Highly palatable browse to livestock and wildlife. Erosion control.

CURLLEAF MOUNTAIN-MAHOGANY
(*Cercocarpus ledifolius* Nutt.)

Propagation/Reproduction:
- Natural: Flowers from May to July and seeds dispersed by August and September.
- Artificial Establishment: Difficult to establish by direct seeding and seedling growth rate is slow. Germination rates are reported to be good. Sow in the fall or winter, generally within mixtures of other plants to add diversity. Poor success with transplanting.
- Colonizing Ability: Persistence is good once established but the rate of natural spread is only fair. May form closed stands.
- Habit: Evergreen, bushy shrub or small tree, 1 to 6 m (3 to 20 ft) tall. Often multi-trunked.

Habitat:
- Soil: Dry, clayey to coarse textured soils on exposed mountainous slopes and rocky ridges.
- Elevation: 1,950 to 2,700 m (6,500 to 9,000 ft) in Colorado.
- Distribution: Intermountain West, Montana to Arizona.
- Precipitation Range: Semi-arid.
- Tolerances: Sensitive to drought and frost. Fair tolerance of browsing.

Uses: Seeds are food for small mammals and browse is highly preferred by large game. Provides winter shelter for wildlife. Erosion control. Preferred firewood.

DESERT BITTERBRUSH
(*Purshia glandulosa* Curran.)

Propagation/Reproduction:
- Natural: Flowers in April to May and seed ripens during June and August.
- Artificial Establishment: Successful propagation by direct seeding with excellent germination and fair initial growth rate. Good seedling tolerance of drought. Good seed production and handling. Seed in late fall and winter with stratification. Easily transplanted.
- Colonizing Ability: Good persistence but fair rate of spread. Good competitive ability.
- Habit: Deciduous, dense shrub, 1 to 2 m (3 to 7 ft) tall with an equal spread. Deep extensive root systems, capable of nitrogen fixation.

Habitat:
- Soil: Well drained, sandy to clayey soils.
- Elevation: Sea level to > 3,000 m (10,000 ft).
- Distribution: Northwestern Arizona and southwestern Utah to southeastern Nevada and California.
- Precipitation Range: Semi-arid.
- Tolerances: Drought tolerant. Good resistance to grazing.

Uses: Soil stabilization. Palatable browse.

DOUGLAS RABBITBRUSH
(*Chrysothamnus viscidiflorus* (Hook.) Nutt.)

Propagation/Reproduction:
- Natural: Reproduces by seeds and sprouts. Blooms in late summer and fall and seed matures from late summer until winter.
- Artificial Establishment: Fair establishment by direct seeding with excellent germination rates and fair growth rates. Best to seed in late fall or early spring. Also by transplanting wildlings or container stock. Poor results with cuttings.
- Colonizing Ability: Persistence is good and rate of spread is excellent. May be competitive with grass and forbs due to generalized root system.
- Habit: Warm season, deciduous, round-topped, small shrub, 0.3 to 1 m (1 to 3 ft) tall, with spread of equal dimension. Deep, widely spreading, generalized root system.

Habitat:
- Soil: Basic, well-drained, clayey to coarse-textured deep soils. Broad range of adaptability. Will grow in weakly acid soils.
- Elevation: 1,500 to 7,000 m (5,000 to 10,000 ft).
- Distribution: New Mexico and Arizona north to Montana. Prevalent in Intermountain Region.
- Precipitation Range: 15 to 50 cm (6 to 20 in).
- Tolerances: Fair salt, good drought tolerance. Fair shade tolerance. Sprouting ability affords it good fire and grazing tolerance.

Uses: Fair to poorly utilized browse. Provides cover for birds and small mammals. Good for slippage and erosion control.

FOUR-WING SALTBUSH
(*Atriplex canescens* (Pursh)(Nutt.)

Propagation/Reproduction:

Natural: Flowers from May to August, depending on zone. Seeds mature 14 to 16 weeks after blooming.

Artificial Establishment: Propagated fairly easily by direct seeding with rapid seedling growth. Rate of sowing 0.56 kg /ha (0.5 lb/ac); also by stem cuttings or by transplants. Short stratification period allows it to be seeded with grass and forbs.

Colonizing Ability: Good persistence and average rate of natural spread.

Habit: Evergreen, brittle, erect, branching from base, 0.6 to 2 m 〉 2 to 6 ft) tall. Deep and extensive root system. Capable of nitrogen fixation (endotropic mycorrhizae). Has broad genetic entities.

Habitat:

Soil: Alkaline, well-drained, sandy to clayey soils. Best on calcareous soils.

Elevation: Sea level to 2,440 m (8,000 ft).

Distribution: From Canada to Mexico and Great Plains to Pacific Coast. One of the most widespread and adaptable shrubs in western United States.

Precipitation Range: 〉 15 to 38 cm (〉 6 to 15 in).

Tolerances: Good drought and salt tolerance. Poor grazing tolerance.

Uses: Good species for surface stabilization and slippage control. Highly nutritious and palatable for livestock and wildlife.

FRINGED SAGEBRUSH
(*Artemisia frigida* Willd.)

Propagation/Reproduction:

Natural: Flowers in late summer or fall and seed matures in September and October.

Artificial Establishment: Fair establishment by seed but poor seedling growth rate and good seedling drought resistance; late fall or early spring.

Colonizing Ability: Fair competitor and fair shade tolerance but prefers open areas. Good rate of natural spread.

Habit: Cool season, erect, branching from woody decumbent base; height of 10 to 35 cm (4 to 14 in) and spread of 15 to 30 cm (6 to 12 in); moderately deep, fibrous root systems.

Habitat:

Soil: Neutral to slightly basic, well-drained, medium-texture soils; mostly on foothills and rocky or gravely sites; prefers open, disturbed sites.

Distribution: From west Texas through most of the coal region of Western U.S.

Precipitation Range: 20 to 50 cm (8 to 20 in).

Tolerances: Good drought tolerance and fair salt tolerance; good grazing tolerance.

Uses: Good browse for sheep and goats and winter feed for elk and deer; surface stabilization.

GAMBEL OAK
(*Quercus gambelii* Nutt.)

Propagation/Reproduction:

Natural: Fruit ripening and seed dispensal occur in fall.

Artificial Establishment: Only fair to poor establishment by direct seeding. Not transplanted easily.

Colonizing Ability: Persistence is good once established but natural spread is slow. Fair compatibility with other plants.

Habit: Cool season, deciduous, commonly thicket-forming shrub or small tree to 5 m (16 ft) tall, but can be to 16 m (50 ft).

Habitat:

Soil: Sandy and gravelly loams on foothills, canyons, and lower mountain slopes.

Elevation: 1,200 to 2,440 m (4,000 to 8,000 ft).

Distribution: West Texas to Arizona north through Utah and Colorado to southern Wyoming.

Precipitation Range: 40 to 50 cm (16 to 20 in).

Tolerances: Good grazing tolerance.

Uses: Fairly palatable browse for livestock and big game. Acorns also food for wildlife and livestock. High tannic acid in young shoots can be toxic to livestock. Good cover for wildlife. Good soil builder. Good soil stabilizer.

GARDNER SALTBUSH
(*Atriplex gardneri*)(moq. Standl.)

Propagation/Reproduction:

Natural: Flowers in late spring and seed matures beginning in August.

Artificial Establishment: Poor initial establishment with fair germination and good growth rates. Seed production is fair. Transplanted easily or propagated by stem cuttings.

Colonizing Ability: Fair persistence and rate of spread. Fairly compatible with other plants and good competitive ability.

Habit: Evergreen, woody-based, well-branched, creeping small shrub, 20 to 50 cm (8 to 20 in) tall. Well-branched, deep root system.

Habitat:

Soil: Basic, clayey soils.

Elevation: 1,200 to 2,100 m (4,000 to 6,000 ft).

Distribution: Intermountain Region on dry slopes and ridges.

Precipitation Range: 13 to 30 cm (5 to 12 in).

Tolerances: Grazing tolerant. Good drought tolerance. Excellent salt tolerance.

Uses: Winter browse for sheep and cattle. Good soil stabilizer due to spreading habit.

GOLDEN CURRANT
(*Ribes aureum* Pursh.)

Propagation/Reproduction:
- Natural: Flowers in spring and seed matures in summer (June and July).
- Artificial Establishment: Established easily by seed with good seedling growth rate. Requires cold stratification in the spring. Fall is preferred time to seed. Also propagated by stem and root cuttings, or container stock.
- Colonizing Ability: Good persistence and natural spread. Tolerant of moderate shade. Good compatibility with associates and good competitive ability. Spreads by rhizomes.
- Habit: Deciduous clumped shrub ranging in height from 1 to 2 m (3.3 to 6.5 ft) and in width from 1 to 1.5 m (3.3 to 5 ft). Rhizomatous spreading root system.

Habitat:
- Soil: Slightly acidic (pH 6.0) to weakly basic, well-drained, loamy soils. Also adaptable to coarse-textured soils. Prefers fertile soil.
- Elevation: 760 to 2,000 m (2,533 to 8,000 ft).
- Distribution: Most of Western Coal Region of the United States, including the Texas panhandle. Generally on mesic sites.
- Precipitation Range: 30 to 50 cm (12 to 20 in).
- Tolerances: Good grazing tolerance. Tolerant of moist sites but only fair tolerance of drought. Fair fire tolerance. Poor salt tolerance.

Uses: Soil stabilization. Excellent big game browse. Avoid planting with five-needled pines because this is an alternate host of white pine blister rust.

GRAY MOLLY SUMMER CYPRESS
(Kochia americana var. Vestita S. Watts)

Propagation/Reproduction:
- Natural: Flowers from June to August.
- Artificial Establishment: Good seed germination rates. Also by stem cuttings.
- Colonizing Ability:
- Habit: Warm season, suffrutescent shrub, 10 to 50 cm (4 to 20 in) tall.

Habitat:
- Soil: Alkaline or saline clay soils.
- Elevation: 1,370 to 1,830 m (4,500 to 6,000 ft).
- Distribution: New Mexico and Arizona, north to Montana and Idaho.
- Precipitation Range: 15 to 25 cm (6 to 10 in).
- Tolerances: Excellent drought and good salt tolerance.

Uses: Winter browse for sheep. Surface stabilization potential on saline mine sites.

GREEN EPHEDRA
(*Ephedra viridis* Coville.)

Propagation/Reproduction:
- Natural: Flowers in spring and seed matures in May to July.
- Artificial Establishment: Good establishment by direct seeding but needs cold stratification; plant before the growing season when soil moisture available. Stem cutting unreliable. Poor rate of natural spread.
- Colonizing Ability: Spreads by roots; fair competitive ability.
- Habit: Erect broom-like branches; range in height from 0.6 to 1.2 m (2 to 4 ft); spread of 0.6 to 1 m (2 to 3 ft). Deep, spreading root system.

Habitat:
- Soil: Well-drained, alkaline, coarse textured. Adapted to dry shallow soils on slopes.
- Elevation: 900 to 2,287 m (3,000 to 7,500 ft).
- Distribution: Utah and northern Arizona to eastern California.
- Precipitation Range: 20 to 35 cm (8 to 14 in).
- Tolerances: Good salt tolerance and excellent drought resistance. Intolerant of high water table.

Uses: Winter browse for deer and livestock; less palatable in the summer. Good potential for erosion control. Sand dune stabilization as it withstands soil encroachment.

LEADPLANT AMORPHA
(*Amorpha canescens* Pursh.)

Propagation/Reproduction:
- Natural: Flowers in June and July and seed matures in August and September.
- Artificial Establishment: Established easily by direct seeding with an excellent seedling growth rate and good seedling tolerance of droughty conditions. Untreated seed in late fall and scarified seed in spring. Also by cuttings of green stem in early summer and hard stem cuttings in fall. Suckers also can be used.
- Colonizing Ability: Good persistence and compatibility with grasses and seeded plants.
- Habit: Warm season, gray-canescens, low shrub, 30 to 100 cm (12 to 40 in). Leguminous plant capable of nitrogen fixation.

Habitat:
- Soil: Slightly acidic to moderately basic, silty to sandy-textured soils.
- Elevation: 1,050 to 1,350 m (3,500 to 4,500 ft) in Colorado.
- Distribution: Great Plains from North Dakota to central Texas. Plains and hills.
- Precipitation Range: 37 to 50 cm (15 to 20 in).
- Tolerances: Good drought and shade tolerance. Resistant to fire. Intolerant of close grazing.

Uses: Palatable and nutritious browse. Watershed cover.

LONGLEAF SNOWBERRY

(*Symphoricarpos longiflorus* Gray)

Propagation/Reproduction:

Natural: Flowers from early to late summer and seed matures from late summer to fall.

Artificial Establishment: Fair establishment by seeding with poor seedling growth rate and fair seedling drought tolerance. Also by stem cuttings.

Colonizing Ability: Good persistence and compatible with associates. Good natural spread.

Habit: Deciduous, low, spreading shrub 50 to 100 cm (20 to 40 in) tall. Fibrous taproot.

Habitat:

Soil: Basic and acid, well-drained, dry soils.

Elevation: 1,220 to 1,830 m (4,000 to 6,000 ft).

Distribution: Oregon south to Texas and California.

Precipitation Range: Mesic sites.

Tolerances: Excellent tolerance to grazing. Fair drought tolerance and poor salt tolerance.

Uses: Soil stabilization. Poorly palatable browse. Good for plantings of woody draws on mesic foothills.

MARTIN CEANOTHUS

(*Ceanothus martinii* M. E. Jones)

Propagation/Reproduction:

Natural: Flowers in May and June and seeds mature in late summer.

Artificial Establishment: Good establishment by direct seeding with fair rate of germination and initial growth rate. Fire helps seed germination. Transplanted easily. Difficult seed production and handling.

Colonizing Ability: Excellent persistence and fair rate of spread. Compatible with associated plants.

Habit: Deciduous, small or large shrub, 30 to 120 cm (1 to 4 ft) tall. Generalized root system, capable of root sprouting and layering. A nitrogen fixer.

Habitat:

Soil: Slightly acid to weakly basic, well-drained, medium-textured soils. Adaptable to rocky and shallow soils.

Elevation: About 2,250 m (7,500 ft).

Distribution: Utah and vicinity. Narrow range.

Precipitation Range: 40 to 50 cm (16 to 20 in).

Tolerances: Good grazing tolerance. Poor salt tolerance. Moderate shade tolerance. Fair drought tolerance. Root sprouting provides fire resistance.

Uses: Highly palatable browse for sheep and cattle and wildlife; provides cover for birds and small mammals. Excellent for soil stabilization. Generally an optional species in game range seeding.

MAT SALTBUSH

(*Atriplex corrugata*)

Propagation/Reproduction:

Natural: Flowers April to June and seeds ripen in July and August.

Artificial Establishment: Difficult to germinate and establish by seed. Can be propagated by stem cuttings and is transplanted easily.

Colonizing Ability: Good competitive ability. Apparently slow rate of natural spread.

Habit: Evergreen, dense, prostrate shrub, 5 to 10 cm (2 to 4 in) high; spreads of 30 to 60 cm (1 to 2 ft). Deep, spreading root system. Branches produce adventitious roots with soil contact.

Habitat:

Soil: Alkaline clay (from mancus shale formation).

Elevation: 1,220 to 2,130 m (4,000 to 7,000 ft).

Distribution: Eastern Utah, western Colorado, and northwestern New Mexico. On dry ridges and slopes.

Precipitation Range: 10 to 25 mm (4 to 10 in).

Tolerances: Excellent salt and drought tolerance.

Uses: Browse for sheep in the summer and fall. Good potential for soil stabilization on harsh saline. Alkaline sites, but stands generally sparse.

MEXICAN CLIFFROSE

(*Cowania mexicana* Don.)

Propagation/Reproduction:

Natural: Flowers in early spring; seeds mature in July and August or later.

Artificial Establishment: By direct seeding with fair germination. Can be seeded with forbs and grasses because of the short stratification. Seed in late fall or early winter. Transplant of container stock also possible.

Colonizing Ability: Slow rate of stand establishment.

Habit: Evergreen shrub to small tree reaching height of 0.9 to 6 m (3 to 20 ft). Stiff and erect stems. Capable of nitrogen fixation.

Habitat:

Soil: Mostly on limestone areas but adaptable to most soils. Has performed well on harsh and shallow soils.

Elevation: 1,220 to 2,440 m (4,000 to 8,000 ft).

Distribution: Most of Western United States.

Precipitation Range: 30 to 50 cm (12 to 20 in).

Tolerances: Fair seedling drought and shade tolerance. Strongly drought tolerant once established. Frost sensitivity. Intolerant to fire. Grazing tolerant.

Uses: Browse for livestock and deer. Soil stabilization.

NUTTALL SALTBUSH
(*Atriplex nuttallii* Wats.)

Propagation/Reproduction:

Natural: Flowers from May to June and seed matures from August until November.

Artificial Establishment: Excellent results with direct seeding; good seedling vigor but slow growth rate. Seed in spring or fall when moisture is sufficient. On difficult sites by transplant stock.

Colonizing Ability: Poor competitive ability due to low stature and slow growth. Best to sow separately. Other plants may outcompete Nuttall saltbush on harsh saline sites.

Habit: Warm season, suffruticose, small shrub, 15 to 90 cm (0.5 to 3 ft) tall. Well-branched, shallow to moderately deep root system.

Habitat:

Soil: Basic, clay soils.

Elevation: 1,220 to 2,287 m (4,000 to 7,500 ft).

Distribution: Intermountain West and vicinity.

Precipitation Range: 13 to 30 cm (5 to 12 in).

Tolerances: Salt tolerant. Cold tolerant. Resistance to fire due to root sprouting. Susceptible to grazing.

Uses: Palatable browse for livestock and big game, especially in winter. Soil stabilization on disturbed sites. Good potential for mined soils.

PROSTRATE KOCHIA OR PROSTRATE SUMMER-CYPRESS
(*Kochia prostrata* L.(Schrad.))

Propagation/Reproduction:

Natural: Flowers from July to September.

Artificial Establishment: Excellent propagation by direct seeding with vigorous seedling growth rate and seedling tolerance of droughty conditions. Variable field germination. Very short seed viability (1 yr). Also can be transplanted.

Colonizing Ability: Good competitive ability and good rate of natural spread once established. May outcompete other desirable species. Long-lived.

Habit: Cool and warm season, perennial, half-shrub. Erect annual branching from decumbent woody base; reaches height of 30 to 90 cm (1 to 3 ft). Extensively branched root system.

Habitat:

Soil: Basic, coarse-textured soils; sandy to stony to sodic soils, depending on ecotype.

Distribution: Introduced from arid and semi-arid regions of Eurasia. Well adapted to Intermountain Region.

Precipitation Range: 20 to 45 cm (8 to 18 in).

Tolerances: Excellent tolerance to drought and salinity. Exceptionally well suited for mined soils of low fertility. Poor grazing resistance.

Uses: Good browse for livestock and big game. Palatability variable.

RUBBER RABBITBRUSH
(*Chrysothamnus nauseosus* (Pall.)(Britt.))

Propagation/Reproduction:

Natural: Seeds ripen over long period from late summer to late fall.

Artificial Establishment: Established easily by direct seeding and vigorous seedling growth. Can be transplanted (in spring). Vegetative propagation is poor.

Colonizing Ability: Spreads aggressively from seed. Can compete with seeded grass. Good persistence.

Habit: Height ranges from 0.3 to 2.4 m (1 to 8 ft) with a spread ranging from 0.6 to 1 m (0.2 to 3.3 ft). Dense, multi-branched deciduous shrub with deep root system.

Habitat:

Soil: Basic, sandy to clayey deep soils. Generally prefers less stressful sites.

Elevation: 610 to 2,440 m (2,000 to 8,000 ft).

Distribution: Western Texas north to British Columbia. Prevalent in Great Basin.

Precipitation Range: 20 to 40 cm (8 to 16 in).

Tolerances: Tolerant of both drought and high water. Moderately salt tolerant.

Uses: Wildlife browse but can be toxic, especially to cattle. Soil stabilization plantings.

Comments: Less palatable subspecies can be used to discourage grazing for soil stabilization plantings.

SASKATOON SERVICEBERRY
(*Amelanchier alnifolia* Nutt.)

Propagation/Reproduction:

Natural: Flowers from May to June and fruit matures from July to September.

Artificial Establishment: Fair establishment by direct seeding or by root cuttings. Can be transplanted from nursery stock. Fair seedling growth rate, seeding in late fall and spring. Transplanted in the spring.

Colonizing Ability: Good persistence but fair natural spread. Good compatibility.

Habit: Warm-season species. Reaches height of 0.9 to 4.5 m (3 to 15 ft).

Numerous and branching stems. Deep and superficial roots.

Habitat:

Soil: Medium to clayey textures. Prefers well-drained, deep, medium-textured soil. Occurs on weakly acid to weakly basic soils.

Elevation: Sea level to 2,700 m (9,000 ft).

Distribution: Western Texas and New Mexico north to Montana and extending to West Coast.

Precipitation Range: 35 to 50 cm (14 to 20 in).

Tolerances: Good grazing tolerance. Fair drought tolerance but poor tolerance to salt and flooding. Good fire tolerance.

Uses: Soil stabilization and erosion control. Preferred winter browse for big game; fair to good for livestock.

SHADSCALE

(*Atriplex confertifolia* (Torr. & Frem.) S. Wats.)

Propagation/Reproduction:

Natural: Flowers from late March to June and utricles mature about 15 weeks after blooming.

Artificial Establishment: Poor establishment by direct seeding. Better propagation by stem cuttings from late winter. Establishes well by transplanting in early spring.

Colonizing Ability: Good natural rate of spread after well established.

Habit: Compact, spinescent, decumbent, reaching maximum heights of about 0.8 m (2.6 ft); generally 15 to 90 cm (6 to 36 in) tall; deep and spreading root system; cool season.

Habitat:

Soil: Alkaline, fine-textured to gravelly soils.

Elevation: 460 to 2,135 m (1,500 to 7,000 ft).

Distribution: New Mexico to Canada and west to eastern California, Oregon, and Washington. Prevalent in Great Basin and Colorado Plateau.

Precipitation Range: 10 to 20 cm (4 to 8 in).

Tolerances: Excellent salt and drought tolerance. Spines provide grazing resistance.

Uses: Palatable despite the spines; good winter browse for livestock; erosion and soil slippage control, especially on saline sites.

SIBERIAN PEA SHRUB

(*Caragana arborescens* Lam.)

Propagation/Reproduction:

Natural: Flowers from April to June and seed matures from June to August.

Artificial Establishment: Fairly easy to establish by direct seeding with an excellent germination rate and fair seedling growth rate. Seedling is tolerant of droughty conditions. Seed in late summer or spring, generally in mixtures, using 1 lb/ac or less. Also by stem or root cuttings. Transplanting ability is excellent.

Colonizing Ability: Persistence and rate of spread once established is fair. Good competitor and only fair compatibility with forbs and grasses. A long-lived plant.

Habit: Deciduous, upright shrub or small tree, 1.5 to 4.5 m (5 to > 15 ft). Extensive and branched moderately deep root system.

Habitat:

Soil: Strongly basic (pH 10 to 11) and strongly acid (pH 4.0), well-drained soils of moist textural classes. Adaptable to infertile, shallow, and rocky soils.

Distribution: Northern Great Plains through central Utah and Colorado. Introduced from Siberia and Manchuria.

Precipitation Range: 30 to 50 cm (12 to 20 in).

Tolerances: Resistant to grazing. Intolerant of wet soils. Moderately salt tolerant. Excellent drought tolerance. Fair shade tolerance. Winter-hardy.

Uses: Mined-land soil stabilization. Windbreak planting. Fair browse in spring and summer, but generally poorly palatable to livestock. Nesting site and food for birds.

SILVER BUFFALOBERRY
(Shepherdia Argentea (Pursh) Greene.)

Propagation/Reproduction:

Natural: Flowers in spring and early summer and seed matures in late summer through fall.

Artificial Establishment: Difficult to establish by direct seeding with fair germination rate and seedling growth rate. In the fall or spring if stratified. Also propagated by root sprouts or wildlings or container stock.

Colonizing Ability: Good persistence once established with fair natural rate of spread. Strong competitive ability so often incompatible with other less competitive plants. Spreads by root sprouting.

Habit: Deciduous, thorny, thicket-forming large shrub. May reach height of 7 m (23 ft). Extensive and well-branched, shallow root system, capable of nitrogen fixation. Rhizomatous.

Habitat:

Soil: Basic, well-drained, medium coarse soils. Common on seasonally wet sites.

Elevation: 1,350 to 2,250 m (4,500 to 7,500 ft) in Colorado.

Distribution: From eastern California to central New Mexico and Kansas, north to Montana. Generally in valleys along streams or in low meadows and other wet sites.

Precipitation Range: 30 to 50 cm (12 to 20 in).

Tolerances: Good tolerance of grazing. Salt tolerant. Poorly tolerant of shade. Good drought tolerance. Fair fire tolerance. Shade intolerant.

Uses: Soil stabilization. Excellent browse for wildlife, but poorly palatable to cattle. Windbreak plantings. Live fencing.

SILVER SAGEBRUSH
(*Artemisia cana* Pursh.)

Propagation/Reproduction:

Natural: Flowers in late summer and fruit matures in fall.

Artificial Establishment: Fair establishment by seeding at any time of year when moisture is available; seed about 0.4 to 0.8 kg/ha (0.5 to 1.0 lb/ac).

Colonizing Ability: Compatible with herbaceous associates but poor shade tolerance. Forms extensive colonies by rhizomes. Good rate of natural spread both by seed and vegetatively.

Habit: Warm season, evergreen, woody-based small shrub 1 to 1.5 m (3 to 5 ft) tall. Generally well-branched rhizomatous root system. Aromatic.

Habitat:

Soil: Weakly acidic to moderately basic, well-drained, medium-textured soils; generally on valley terraces and uplands.

Elevation: 1,500 to 3,000 m (5,000 to 10,000 ft) in Canada.

Distribution: Northern New Mexico to Montana and west to central California, Oregon and Washington; prevalent in the Intermountain West.

Precipitation Range: 25 to 36 cm (10 to 14 in).

Tolerances: Intolerant of wet sites; good drought tolerance; poor shade tolerance; good tolerance to grazing.

Uses: Browse for sheep and big game in winter; soil stabilization.

SKUNKBUSH SUMAC
(*Rhus trilobata* Nutt.)

Propagation/Reproduction:

Natural: Flowers when leafless in early spring and seed matures in late summer to fall. Also spreads by root sprouting.

Artificial Establishment: Established fairly easily by direct seeding, with good seedling competitive ability and drought tolerance. Poor seed germination. Hard seed coat; requires scarification. Propagated readily by stem or root cuttings.

Colonizing Ability: Rhizomatous roots; forms thickets. Excellent persistence once established but slow to spread. Only fairly compatible with grass and forbs.

Habit: Cool season, deciduous, multi-branched and dense shrub. Reaches height of 0.6 to 3 m (2 to 10 ft) and equal to greater spreads. Rhizomatous spreading roots and extremely branched deeper roots.

Habitat:

Soil: Slightly basic, well-drained soils of most textural classes.

Elevation: 1,260 to 3,300 m (4,200 to 11,000 ft).

Distribution: Most of the Western Coal Region of United States. Generally found on shallow and dry rocky foothills.

Precipitation Range: 25 to 50 cm (10 to 20 in).

Tolerances: Excellent tolerance of grazing. Fair drought tolerance and poor salt tolerance. Intolerant of flooding. Poor tolerance of shade. Fire tolerant.

Uses: Good browse for big game but poorly palatable to livestock. Soil stabilization and windbreaks.

SPINELESS HOPSAGE
(*Grayia brandegei*)

Propagation/Reproduction:

Natural: Flowers from June to August and the seed matures from September to October.

Artificial Establishment: Fair propagation by seed with excellent germination rate and good initial seedling growth rate. Needs cold stratification and protection from rodents and rabbits.

Colonizing Ability: Good persistence and fair rate of natural spread once established. Fair compatibility with other plants.

Habit: Deciduous small shrub, 0.5 to 1 m (1.7 to 3.3 ft) tall with a spread of 0.3 to 1.2 m (1 to 4 ft). Spreading root system. Drops leaves early in summer with stress.

Habitat:

Soil: Basic, silty clay loam soil derived from shale formations.

Elevation: 900 to 2,100 m (3,000 to 7,000 ft).

Distribution: Upper Colorado River drainage.

Precipitation Range: 25 to 40 cm (10 to 16 in).

Tolerances: Excellent tolerance to grazing and good drought tolerance. Fair salt tolerance.

Uses: Good potential for soil stabilization. Good spring, summer, and winter browse for livestock and wildlife. May contain toxic levels of selenium on soils containing selenium.

SPINY HOPSAGE

(*Grayia spinosa* (Hook.) Moq.)

Propagation/Reproduction:

Natural: Flowers from April to June and seed matures from June to August.

Artificial Establishment: Fair establishment by direct seeding with only a poor seedling growth rate. Generally seeded in mixtures as an option species. Seed in early fall or spring. Also by root or stem cuttings.

Colonizing Ability: Good competitor when established but seedlings have poor competitive ability and drought resistance. Performs best in full sunlight but also grows in open woodlands. Fair to poor ability to spread.

Habit: Warm season, deciduous, spinescent, much branched and spreading shrub that reaches height of 0.3 to 1.2 m (1 to 4 ft) and about equal width. Shallow to moderately deep spreading root system. Begin growth in late winter and early spring. Often evergreen in southern habitat. Generally dormant in summer. Loses leaves in summer.

Habitat:

Soil: Alkaline to near neutral, shallow sandy to clayey soils. Calcareous sites.

Elevation: 900 to 2,100 m (3,000 to 7,000 ft).

Distribution: Intermountain West and vicinity on plains and foothills.

Precipitation Range: 25 to 40 cm (10 to 16 in).

Tolerances: Excellent drought tolerance. Fair salt tolerance. Fair grazing tolerance.

Uses: Fall winter and spring browse for deer, goats, and sheep. Good for surface stabilization.

SPINY SAGEBRUSH OR BUD SAGE

(*Artemisia spinescens* (DC.) Eat.)

Propagation/Reproduction:

Natural: Flowers from March to June and sheds seeds in June and July.

Artificial Establishment: Can be established by seed, though germination rate is slow and production and handling of seed is difficult. Also by stem cuttings. Fair establishment by transplant.

Colonizing Ability: Good persistence and rate of spread once established. Generally compatible with associates.

Habit: Cool season, well-branched, rigid, spinescent, evergreen, small shrub, 20 to 25 cm (4 to 10 in) tall with about an equal spread. Shallow and fibrous root system.

Habitat:

Soil: Basic, well-drained, shallow loamy soils.

Elevation: 1,200 to 1,620 m (4,000 to 5,400 ft).

Distribution: Central New Mexico to California and north to central Washington and Montana. Prevalent in Great Basin.

Precipitation Range: 20 to 35 cm (8 to 14 in).

Tolerances: Resistant to browsing; however, can be eliminated by heavy spring grazing. Excellent drought tolerance and fair salt tolerance.

Uses: Good browse for sheep and wildlife in winter and early spring. Surface stabilization.

TRUE MOUNTAIN MAHOGANY

(*Cercocarpus montanus* Raf.)

Propagation/Reproduction:

Natural: Flowers from May to June and seed matures by August.

Artificial Establishment: Poor propagation by direct seeding; seedlings susceptible to drought and frost action. Plant unstratified seed in the fall. Also by stem cutting or by transplanting.

Colonizing Ability: Good persistence and fair rate of natural spread. Can form pure stands.

Habit: Cool season, one-half evergreen, shrub or small tree, 1 to 6 m (3.3 to 20 ft) tall. Deep and wide spreading root system, capable of nitrogen fixation.

Habitat:

Soil: Well drained, slightly acid to basic, medium to clay textures on south- or west-facing slopes.

Elevation: 1,220 to 2,440 m (4,066 to 8,133 ft).

Distribution: South Dakota to Texas and west to Oregon and California

Precipitation Range: 14 to 50 cm (5 to 20 in).

Tolerances: Good to fair drought tolerance but poor salt tolerance. Good tolerance of lime. Intolerant of flooding and high water table. Tolerant of grazing.

Uses: Excellent browse for livestock and wildlife.

UTAH SERVICEBERRY
(*Amelanchier utahensis* Koehne)

Propagation/Reproduction:

Natural: Flowers in late spring and early summer and seed matures in late summer.

Artificial Establishment: Fair establishment by seed with good seed germination but relatively poor early seedling growth rate and fair seedling tolerance of drought. Good final establishment. Seed requires cold stratification. Also can be propagated by root cuttings.

Colonizing Ability: Good persistence once established and fair rate of spread. Generally compatible with other plants.

Habit: Cool season, deciduous, extensively branched erect shrub, 1 to 4 m tall (3 to 12 ft). Spread of 0.6 to 4.5 m (2 to 15 ft). Deep and spreading root system that is capable of suckering.

Habitat:

Soil: Slightly basic, well-drained, medium- to coarse-textured soils.

Elevation: 1,200 to 2,500 m (4,000 to 8,000 ft).

Distribution: Great Basin and vicinity. Generally on dry ridges and slopes.

Precipitation Range: 35 to 50 cm (14 to 20 in).

Tolerances: Good grazing resistance. Fair drought tolerance but poor tolerance of saline soils.

Uses: Soil erosion and slippage control. Good browse for livestock and used by deer during winter months.

WAR CURRANT OR SQUAW CURRANT
(*Ribes cereum* Dougl.)

Propagation/Reproduction:

Natural: Flowers from April to June and seed matures by August.

Artificial Establishment: Poor establishment by direct seeding. Somewhat better by transplant.

Colonizing Ability: Poor rate or natural spread but good persistence.

Habit: Cool season, much-branched, thornless shrub, 0.6 to 1.2 m (2 to 4 ft) tall.

Habitat:

Soil: Acid to basic soils; dry rocky open slopes and ridges.

Elevation: 1,200 to 3,300 m (4,000 to 11,000 ft) in Colorado.

Distribution: Montana to New Mexico.

Tolerances: Good grazing tolerance.

Uses: Poorly palatable to livestock and poor browse for wildlife. Soil stability.

WESTERN SNOWBERRY
(*Symphoricarpos occidentalis* Hook.)

Propagation/Reproduction:

Natural: Flowers in late spring and early summer and seed matures from summer to fall.

Artificial Establishment: Fair establishment by direct seeding in fall (warm-stratified) or in spring (moist-prechilled). Also by cuttings or transplanting wildlings.

Colonizing Ability: Strongly competitive and forms dense colonies. Generally excludes grass and forbs. Spreads by rhizomes. Prefers disturbed, open sites. Good to excellent ability to spread naturally.

Habit: Deciduous, dense colony forming short shrub, generally 0.5 to 1.5 m (20 to 60 in) tall. Superficial, well-branched road system with intermittent rhizomes.

Habitat:

Soil: Weakly basic and slightly acidic soils of most textural classes.

Elevation: 1,050 to 2,550 m (3,500 to 8,500 ft) in Colorado.

Distribution: Great Plains and Rocky Mountains. Hillsides, valleys, along streams, draws, and similar wet areas.

Precipitation Range: 30 to 50 cm (12 to $>$ 20 in). Mesic areas.

Tolerances: Tolerant of flooding but not of permanently high water table. Excellent drought tolerance. Tolerant of grazing and fire. Tolerant of partial shade.

Uses: Good browse for deer, but poorly palatable for livestock. Soil stabilization. Good for plantings of woody draws on mesic sites.

WESTERN VIRGINSBOWER

(*Clematis Ligusticifolia* Nutt.)

Propagation/Reproduction:

Natural: Flowers from June to August and seed matures in fall and winter.

Artificial Establishment: Fair establishment by direct seeding with slow rates of germination and initial growth. Collection and handling difficulties. Limits propagation by seeds. Established more easily by transplant.

Colonizing Ability: Tends to invade disturbed sites and has fair to good rate of natural spread.

Habit: Woody-based climbing vine, 3 to 〉 6 m long. Fibrous, shallow root system.

Habitat:

Soil: Weakly acid to moderate alkaline, well-drained, coarse textured soils.

Elevation: 1,500 to 2,550 (5,000 to 8,500 ft) in Colorado.

Distribution: Most of the Western Coal Region of United States. Often on disturbed sites, with some form of support (e.g. trees, slopes, banks).

Precipitation Range: 30 to 50 cm (12 to 20 in).

Tolerances: Fair drought resistance; moderate shade tolerance. Not frost sensitive.

Uses: Soil stabilization on mined soils. Browse for deer. Poorly palatable for livestock.

WINTERFAT

(*Ceratoides lanata* (L.) C.A. Mey.)

Propagation/Reproduction:

Natural: Flowers in March to July and seeds mature from September to November.

Artificial Establishment: Direct seeding with rapid germination and fair establishment rates. Short stratification allows mixed seeding. Frost sensitive in early seedling stage. Transplanted easily.

Colonizing Ability: Good persistence but poor shade tolerance; fair competition with grass; long-lived and adaptable to most sites. Good rate of natural spread.

Habit: Cool season, erect or spreading, reaching heights of 30 to 60 cm (12 to 24 in) and spread of 15 to 45 cm (6 to 18 in); deep and fibrous root system.

Habitat:

Soil: Basic, rocky to clayey soils.

Elevation: Sea level to more than 3,048 m (10,000 ft).

Distribution: Most of Western United States and very prevalent in the Intermountain Salt Desert Range. Mostly on valley floors.

Precipitation Range: 12.5 to 50 cm (5 to 20 in).

Tolerances: Excellent drought tolerance and good salt resistance. Intolerant to high water table and acid soils. Poor grazing resistance.

Uses: Soil stabilization. Highly palatable and nutritious browse to wildlife and livestock.

WOODS ROSE

(*Rosa woodsii* Lindl.)

Propagation/Reproduction:

Natural: Flowers in summer and seed matures from midsummer until fall. Reproduces by seed.

Artificial Establishment: Established fairly easily by seed with good seedling growth rate. Only poor germination. Seed in spring and fall. Propagated readily by root cuttings or by transplanted seedlings.

Colonizing Ability: Excellent persistence once established with fair ability to spread. Aggressive pioneer on open, disturbed site. Fairly compatible with grass and forbs and only moderately competitive.

Habit: Cool season, deciduous, spiny, thicket-forming shrub, reaching height of 0.6 to 3.6 m (2 to 6 ft). Extensively branched, shallow root system. Often rhizomatous. Renew growth in spring.

Habitat:

Soil: Moderately acid to slightly basic, well-drained, loamy to sandy soils. Prefers nonsaline sites.

Elevation: 1,300 to 2,250 m (4,500 to 7,500 ft) in Colorado.

Distribution: Intermountain West and Great Plains to western Texas and eastern Arizona. Most common on dry slopes, plateaus, and plains.

Precipitation Range: 30 to 50 cm (12 to 20 in).

Tolerances: Good grazing tolerance. Intolerant of flooding. Moderate drought tolerance. Moderately shade tolerance. Good tolerance of fire.

Uses: Good browse for big game but only fair for livestock. Excellent for erosion control. Because of thorns this species is better suited for mixed planting.

ARIZONA CYPRESS
(*Cupressus Arizonica* Greene)

Propagation/Reproduction:
Natural: Pollination occurs in late fall through spring and seeds mature 15 to 18 months later.
Artificial Establishment: Good establishment by direct seeding. Seed production, handling, and germination is fair. Seeds need to be stratified and protected from damping-off fungi. Can be transplanted as 1- or 2-year-old seedlings.
Colonizing Ability: Persistence is good once established but only fair rate of natural spread. Seedling is poorly competitive with other plants.
Habit: Evergreen tree, 9.2 to 27 m (30 to 90 ft) tall. Seedling has taproot and lateral roots.

Habitat:
Soil: Gravelly northern slopes or cuts.
Elevation: 915 to 2,440 m (3,000 to 8,000 ft).
Distribution: Arizona, New Mexico, and southern Texas.
Precipitation Range: 40 to 50 cm (16 to 20 in).
Tolerances: Grazing tolerant. Seedling poorly tolerant of droughty conditions. Tolerant of high temperatures.

Uses: Watershed, erosion control and windbreak plantings. Habitat for wildlife. Timber products.

BIGTOOTH MAPLE
(*Acer grandidentatum* Nutt.)

Propagation/Reproduction:
Natural: Flowers from April to May and fruit ripens from August to September.
Artificial Establishment: Good establishment by direct seeding, but slow rate of seedling growth. Transplanted easily.
Colonizing Ability: Moderate rate of natural spread.
Habit: Deciduous shrub to tree, to 12 m (40 ft) tall.

Habitat:
Soil: Similar to Rocky Mountain Maple (*A. glabrum*). Moderately acid to slightly basic, well-drained, porous sandy or gravelly loams. Also on cliffs and rocky canyon sides.
Distribution: Utah and western Wyoming, south to southeastern Arizona and New Mexico.

Uses: Watershed and habitat plantings. Beautiful fall colors.

BUR OAK
(*Quercus macrocarpa* Michx.)

Propagation/Reproduction:
Natural: Flowers from April to June and acorns ripen from August to November.
Artificial Establishment: By direct seeding or by planting container stock. Plant acorns in the fall at rate of about 1,000 per acre. Container stock planted on the more difficult sites; in late winter or early spring.
Colonizing Ability: Establishment required reducing competition from other plants and controlling livestock and small mammal activity.
Habit: Deciduous, spreading, medium-size tree; to 30 m (100 ft) tall.

Habitat:
Soil: Wide range of soils. Acid (pH 4.0) to moderately basic, medium- to coarse-textured soils.
Distribution: The Dakotas and northeast Wyoming and the Midwest south to Texas.
Precipitation Range: 38 to 100 cm (15 to 40 in).
Tolerances: Drought resistant. Intolerant of flooding. Winter-hardy.

Uses: Habitat for wildlife, environmental forestry, watershed protection, and timber products.

DESERT WILLOW
(*Chilopsis linearis* (Cav.) Sweet)

Propagation/Reproduction:
Natural: Flowers from April to August and seed matures from late summer to fall.
Artificial Establishment: By seeding in the spring immediately after the soil warms. Also by cuttings.
Colonizing Ability: Requires protection from other plant competition and grazing to become established. Naturally invades eroded drainages.
Habit: Deciduous, short-lived tree, 3 to 7.5 m (10 to 25 ft) tall. No information on rooting characteristics. Leaf out in spring.

Habitat:
Soil: Neutral to basic, well-drained, sandy to gravelly alluvium.
Elevation: 450 to 1,500 m (1,500 to 5,000 ft).
Distribution: Southern Arizona to southwestern Texas. Generally along streams and dry washes in the desert.
Precipitation Range: Arid zones of Southwest.

Uses: Wildlife cover and soil stabilization. Poorly palatable to livestock.

DOUGLAS-FIR

(*Pseudotsuga menziesii* Franco.)

Propagation/Reproduction:

Natural: Flowers from April to June and seeds mature from July to September.

Artificial Establishment: By direct seeding only under ideal conditions. Generally by container stock in winter and early spring. Also by stem cuttings.

Colonizing Ability: Competitive only after seedling stage. Establishment requires a reduction in competition from other plants and grazing animals.

Habit: Evergreen, medium-size tree, to 39 m (130 ft) tall.

Habitat:

Soil: Moderately acid to neutral, well-drained but moist, medium- to coarse-textured soils.

Elevation: 570 to 3,300 m (1,900 to 11,000 ft). Generally on the north-facing slope at lower elevations.

Distribution: Western Texas to Arizona and north to Montana and Washington.

Precipitation Range: 40 to 127 cm (16 to 50 in).

Tolerances: Fair drought tolerance and shade tolerance. Poor fire tolerance. Poor tolerance of heavy, repeated grazing.

Uses: Watershed and environmental planting. Habitat for wildlife. Timber. Windbreaks.

GREEN ASH

(*Fraxinus pennsylvanica* Marsh.)

Propagation/Reproduction:

Natural: Flowers from March to May and seed matures by September to October.

Artificial Establishment: By unstratified seed in the fall and stratified seed in the spring. Generally established by transplanting seedlings.

Colonizing Ability: Slow and often poor growth on mined lands. Requires protection from competition from other plants for establishment.

Habit: Deciduous, small to medium-size tree, 18 m (60 ft) tall. Shallow and extensive root system. Coppice often being cut.

Habitat:

Soil: Medium- to coarse-textured soils. Generally found on alluvial soils. Moderately basic to strongly acid (pH of 4.0).

Distribution: Central Montana and Wyoming through the Dakotas and most of Eastern United States.

Precipitation Range: 37 to 114 cm (15 to 45 in).

Tolerances: Tolerant of periodic flooding and acid conditions. Good drought tolerance.

Uses: Environmental forestry, shelterbelts, timber production, and shelter and food for wildlife. Poorly palatable to livestock. Good shade tree.

NEW MEXICO LOCUST

(*Robinia neomexicana* A. Gray)

Propagation/Reproduction:

Natural: Flowers from May to June and fruit ripens by September. Also reproduces by suckers.

Artificial Establishment: Fair rate of establishment by direct seeding with fair seedling growth rate. Seedling moderately drought resistant. Also by nursery-stock transplants.

Colonizing Ability: Competitive ability is fair. Established readily on harsh sites. Good rates of natural spread by seed and vegetatively.

Habit: Thicket-forming, spiny shrub or small tree; 1.8 to 7.6 m (6 to 25 ft) tall. Root sprouter.

Habitat:

Soil: Moist soils. On canyon bottoms and north slopes at lower elevations and on rocky slopes and dry ridge tops at higher elevations.

Elevation: 1,220 to 2,590 m (4,000 to 8,500 ft).

Distribution: West Texas to Arizona north through Utah and Colorado.

Tolerances: Resistant to grazing.

Uses: Browse for goats and mule deer. Habitat for wildlife. Shelterbelt and watershed plantings. Shade. Erosion control.

PINYON

(*Pinus edulis* Engelm.)

Propagation/Reproduction:

Natural: Flowers in June (Arizona) and seed ripens in September.

Artificial Establishment: Fair establishment with direct seeding but seedling growth is slow (5 cm in 2 years). Can be transplanted; best results with 2-year-old nursery stock.

Colonizing Ability: Can become a pest. Very long-lived. Root competition for soil moisture maintains widely spaced stands. Highly competitive with herbaceous vegetation. Good rates of natural spread.

Habit: Evergreen, much branched, 4.6 to 14 m (15 to 47 ft) tall. Extensive shallow lateral roots and deep taproots.

Habitat:

Soil: Alkaline, sandy to silty shallow soils. Adapted to calcareous caliche soils.

Elevation: 1,525 to 2,287 m (5,000 to 7,500 ft). May reach altitude of 2,700 m (9,000 ft).

Distribution: Semiarid areas of New Mexico, Arizona, Utah, and Colorado. On very harsh eroded sites.

Precipitation Range: 30 to 46 cm (12 to 18 in).

Tolerances: Drought tolerant. Heat tolerant. May be frost sensitive. Intolerant of shade.

Uses: Habitat for wildlife. Seeds important wildlife food. Landscaping. Timber products.

PONDEROSA PINE
(*Pinus ponderosa* Laws.)

Propagation/Reproduction:

Natural: Flowers from April to June and seed is dispersed from August to September.

Artificial Establishment: By untreated seed in the fall and stratified seed in the spring. But establishment by direct seeding is not reliable. Better success with container stock. Older stock best for mined soils. Competitive vegetation must be removed.

Colonizing Ability: Poor when competing with grass, but generally good rate of natural spread.

Habit: Evergreen, straight trunk, tall, 30 to 60 m (100 to 200 ft). Deep root system.

Habitat:

Soil: Acid to basic (4.5 to 9 pH), well-drained, clay loams to loamy sands. Prefers deep soils but also found on shallow soils.

Elevation: 1,220 to 2,440 m (4,000 to 8,000 ft).

Distribution: Widely distributed through Western Coal Region, from western Dakotas to Montana and south to Arizona and western Texas.

Precipitation Range: 38 to 63 cm (15 to 25 in). Can survive on 18 cm (7 in) of rainfall.

Tolerances: Good drought tolerance. Poor tolerance of saline and sodic soils. Not tolerant of shade. Good fire tolerance.

Uses: Environmental forestry, timber, shelterbelt. Browsed by mule deer, mountain sheep, and white-tailed deer. Some birds and small mammals eat the seeds.

QUAKING ASPEN
(*Populus tremuloides* Michx.)

Propagation/Reproduction:

Natural: Flowers from March to May and seeds mature from May to June.

Artificial Establishment: By container stock or root cuttings. Not propagated by seed.

Colonizing Ability: Spreads by underground runners to form dense colonies.

Habit: Deciduous, short-lived, 6 to 12 m (20 to 40 ft) tall. Extensive and shallow root system. Sprouts from roots.

Habitat:

Soil: Moderately basic to slightly acid, well-drained soils of moist textural classes. Performs best on deep sandy to silty loams.

Elevation: Sea level to upper timberline. At higher elevations on south-facing slopes and lower elevations on north-facing slopes.

Distribution: Most of Western Coal Region.

Precipitation Range: 37 to 75 cm (15 to 30 in) in Rocky Mountains.

Tolerances: Winter-hardy. Shade intolerant. Fire tolerant. Fair browsing tolerance.

Uses: Palatable browse to livestock and wildlife. Seeds eaten by various birds. Provides good cover for watershed protection and soil stabilization at high altitudes. Wood products also are used.

ROCKY MOUNTAIN JUNIPER
(*Juniperus scopulorum* Sarg.)

Propagation/Reproduction:

Natural: Flowers from mid-April to mid-June and fruit mature from mid-September to mid-December.

Artificial Establishment: Direct seeding is difficult and slow. Transplant of bare root stock also difficult.

Colonizing Ability: Long-lived and persistent; natural spread is good. Very slow growing.

Habit: Bushy shrub to a tree with irregular crown and average mature height of about 4.2 m (14 ft).

Habitat:

Soil: Alkaline (pH to 8.0), calcareous eroded soils. Found on shallow limestone, sandstone, lava, adobe, and other soils. On southern exposed rugged sites.

Elevation: 1,525 to 2,745 m (5,000 to 9,000 ft).

Distribution: Scattered throughout Western Coal Region, including west Texas and the Dakotas.

Precipitation Range: 30 to 65 cm (12 to 26 in).

Tolerances: Drought tolerant. Tolerant of very harsh sites where other vegetation does not survive. Grazing tolerant. Resistant to damping-off. Poor tolerance of shade.

Uses: Windbreaks. Wildlife habitat. Timber products.

ROCKY MOUNTAIN MAPLE
(*Acer glabrum* Torr.)

Propagation/Reproduction:
- Natural: Flowers from April to June and seeds mature from August to October.
- Artificial Establishment: Good rates of establishment by direct seeding. Stratification required for spring sowing but not for fall seeding. Transplanting success is fair. Recommend using older nursery stock.
- Colonizing Ability: Persistence generally poor and rate of neutral spread only fair. Poorly competitive with grass and forbs; establishment requires a reduction in competition.
- Habit: Deciduous, dense, low bushy shrub or tree, 1.5 to 9 m (5 to 30 ft) tall, with short trunk. Extensive root system of variable depth.

Habitat:
- Soil: Moderately acid to slightly basic, well drained, porous sandy or gravelly loams. Also on cliffs and rocky canyon sides.
- Elevation: Foothills to 3,000 m (10,000 ft).
- Distribution: New Mexico and Arizona, north to Montana and Washington.
- Precipitation Range: 30 to $>$ 63 cm (12 to $>$ 25 in).
- Tolerances: Tolerant of seasonally flooding. Winter-hardy. Fair to poor drought tolerance and fair shade tolerance. Fire resistant.

Uses: Watershed plantings and wildlife habitat. Fair browse for goats and sheep and good for big game.

RUSSIAN OLIVE
(*Elaeagnus angustifolia* L.)

Propagation/Reproduction
- Natural:
- Artificial Establishment: Fair results with direct seeding. Propagated more easily by transplanting. Nursery stock or wildlings. Good growth rate.
- Colonizing Ability: Long-lived and persistent. Reproduces rapidly on wet sites. Good compatibility with other plants. Good rate of natural spread. Can spread into meadows and become a pest.
- Habit: Late deciduous, shrub to tree, 1 to 12 m (3 to 40 ft).

Habitat:
- Soil: Alkaline harsh sites of wide range of soil textures.
- Elevation: Montane foothills to about 2,440 m (8,000 ft).
- Distribution: Introduced from southern Europe, western Asia, and western Himalayas and well adapted to Intermountain West and Northern and Central Great Plains.
- Precipitation Range: 25 to 50 cm (10 to 20 in).
- Tolerances: High tolerance of alkalinity and salt. Good drought tolerance. Good tolerance to grazing. Winter-hardy. Intolerant of shade. Salt tolerant.

Uses: Shade, live fencing, and windbreaks. Browse for livestock and big game in late fall. Berries are food for birds.

UTAH JUNIPER
(*Juniperus osteosperma* (Torr.) Little)

Propagation/Reproduction:
- Natural: Flowers from March to April and seed ripens by September the 2nd year.
- Artificial Establishment: Poor establishment by direct seeding. Propagated by transplanting bare root stock possible but not with high rate of success.
- Colonizing Ability: Excellent persistence and fair rate of natural spread once established. Poorly compatible with other plants.
- Habit: Evergreen, 4.6 to 9.2 m (15 to 30 ft) tall.

Habitat:
- Soil: Dry, well-drained, rocky or sandy slopes. Calcareous soils.
- Elevation: 915 to 2,700 m (3,000 to 9,000 ft).
- Distribution: Intermountain West and vicinity.
- Precipitation Range: 27.5 to 45 cm (11 to 18 in).
- Tolerances: Drought tolerant. Excellent tolerance of grazing as it is poorly palatable.

Uses: Habitat for wildlife, shelterbelt, and possibly soil stabilization.

Suggested Species Mixtures

Species mixtures provide several advantages over single species (monocultures) and, except for cropland purposes, usually are better suited to fulfilling reclamation goals in the Western Coal Region. A most important goal is long-term stability. Ideally, in a mixture, each species is adapted to one or more of the different environmental conditions and stresses that may occur on the reclaimed area. Thus, with nearly any environmental situation, some of the species in the mixture will remain productive or, at least, persist. Mixtures also are less susceptible than monocultures to decimation by a species-selective pathogen or herbivore. Species mixtures enhance wildlife values by providing a diversity or variety of forages and habitats. Increased productivity, too, may be achieved where plants with different life forms are used in mixtures (Rumbaugh et al. 1981). Once the revegetation objectives are defined, criteria can be set for choosing species and developing mixtures. Because domestic livestock grazing (range) and wildlife habitat are primary land uses in the Western Coal Region, the goal of revegetation often is to establish stands of native species similar to predisturbance stands. Normally, the number and types of species included in reclamation mixtures are less than found in native stands. Usually, 10 or fewer species are planted (Oaks 1982). Even so, these mixtures may offer some of the advantages of native vegetational communities such as more stable cover and productivity, and greater habitat diversity for wildlife.

Mixtures most likely to attain these advantages include species with differing life forms, phenology, physiology, and morphology. Selecting from species that thrive in nearby native communities may be a guide to formulating mixtures of species for reclamation. A mixture that includes different life forms such as grasses, forbs, and shrubs may lead to more efficient use of aboveground growing space and light. Below ground, a mixture of deep-rooted shrubs and shallow-rooted grasses and forbs may access more completely the moisture and nutrients in soil than a monoculture with uniform rooting depth and habit.

Where the climate is appropriate for both warm- and cool-season species, mixtures of the two types may provide forage for a longer period of time than either type alone. Inclusion of nitrogen-fixing species, such as legumes and actinorrhizal plants, will increase and prolong productivity of the stand. In some planting situations, species that can survive extended droughts and those that can survive in wet, poorly drained soils both may be needed. Species tolerant of alkaline or sodic soils or those tolerant of acidic soils may need to be included in some mixtures. Minesoils can vary greatly within a given area in moisture availability, nutrients, and toxic materials; thus, mixtures containing species capable of establishing on all soil types are most likely to provide long-term stability and productivity.

The plant community needs to survive through fluctuations in weather and climate. Some species, usually the most productive ones, will dominate in wet years, but will produce little forage in drought years. A drought-tolerant species may not produce large yields of forage at any time but will provide more consistent, though lower, forage production during dry years.

Species with relatively large seeds may produce seedlings that are more aggressive than small-seeded species. Thus, seeding rates of the large seed may need to be reduced, and small seeds should be sown closer to the surface. The seeding density should be adjusted for the different life forms and growth characteristics. For example, a dense stand of cool-season grasses planted in early spring might prevent the establishment of warm-season grasses that germinate later in the spring. High seeding densities frequently result in establishment of seedlings with low vigor (DePuit et al. 1980). Introduced species often are successful because they have been selected and bred for rapid and aggressive seedling establishment. It is preferable to calculate seeding densities on the basis of number of seeds per unit area rather than on weight of seeds. In this way, the density of each species can be controlled to overcome some of the problems that are related to seedling density.

Fertilization and irrigation often are used to improve the establishment of seeded mixtures, but may affect the success of each species differently (DePuit and Coenenberg 1979). Those species most responsive to fertilization or irrigation tend to dominate the stand and reduce the establishment of less-responsive species. Introduced species often respond to these amendments more than native species. Where a stand of native species is desired, it often is recommended that introduced species be used sparingly or not at all.

Specific mixtures are not described here because none are appropriate for all of the Western Coal Region. In general, an attempt should be made to include the different life forms found locally, such as mixtures of shrubs, grasses, and forbs. Where certain life forms are not available commercially, such as some native legumes, introduced species can be substituted, but care should be taken to avoid those that may outcompete the native species component. Recommendations for mixtures that are used locally can be obtained from State and Federal agencies which are involved with reclamation and range improvement, including State Experiment Stations and Extension Services, the USDI Fish and Wildlife Service and the Bureau of Land Management, the USDA Soil Conservation Service and the Forest Service, and State regulatory agencies which oversee coal-mine reclamation.

Agricultural Situation

Agricultural land in the western United States is land that has been converted from native range and forests to pasture or cropland. Cropland exists in those areas where irrigation water is available or rainfall is sufficient for the land to be economically cropped, and other factors such as high salt content or inadequate drainage do not seriously limit productivity. Land constraints such as steep slopes and rocky soil also limit management for cropland.

Because precipitation and other factors severely limit the amount of land where crops can be grown, pasture is the dominant form of reclaimed agricultural land in the West. Reclaiming agricultural land to pasture is particularly important on steep slopes where continuous cover is required to prevent erosion. Land is reclaimed to pasture where the primary intended use is livestock grazing.

Pasture

Pasture land is defined as "land used primarily for the production of domesticated forage plants, to be grazed by livestock or occasionally cut and cured for livestock feed." Reclaiming mined land to pasture in the West has to be done with the conscious decision that the primary intended use of the land will be grazing by livestock. Other uses, such as recreation and wildlife habitat, are not precluded, but necessarily play a secondary role. This contrasts with the large acreages of natural grasslands in the West known as rangelands. Rangeland is defined as "land on which the natural plant cover is primarily native grasses, forbs, and shrubs valuable for forage." These lands provide recreation and wildlife habitat and function as watersheds in addition to providing forage for livestock. Restoration to rangeland implies that the land will be used for these multiple purposes. The decision on whether land should be reclaimed as rangeland or pasture should be based on the desired land use goal.

Pasture can be established and managed successfully under most climatic conditions encountered in the West. However, the annual precipitation will determine how difficult it is to establish the pasture, what species should be used, and the degree of management needed for maintenance. Pastures in the West can be divided into two major zones based on annual precipitation—arid and semiarid. An arid zone typically has less than 8 inches of precipitation annually while a semiarid zone generally receives 8 to 24 inches of precipitation annually (Packer and Aldon 1978).

Thornburg and Fuchs (1978) have broken the arid and semiarid West into nine major plant-growth regions. Of these, part or all of the Intermountain Desertic Basins, California Valleys, and the Desert Southwest are arid. There is potential for development of pastures on arid soils, including reclaimed mine soils, though few such pastures presently exist. There is a need for forage production for livestock in arid zones as well as a need for erosion control. Improved pastures are well suited to provide both.

Establishment of the desired species in arid zones often is difficult, especially when the limited precipitation is variable and unpredictable. Maintaining repeated success in establishing pasture usually requires the addition of some supplemental water. Ries and Day (1978) reviewed much of the information currently available on irrigation for plant establishment on reclaimed land.

Careful management of arid-zone pastures is essential. Overgrazing alone on an arid-zone pasture can be sufficient to destroy its integrity. These pastures also must be grazed at the proper time of the year, and other management practices such as fertilization, burning, and mowing must be done with care. Improved forage for livestock can be produced on properly managed arid-land pastures.

Semiarid climatic zones make up most of the remaining land in the Western Coal Region with the exception of some mountainous areas and the northern Pacific Coast. The higher rainfall of semiarid zones, especially where annual precipitation is greater than 12 inches, makes establishment and management of pastures somewhat easier than in arid zones. Current research shows that the establishment, management, and use of reestablished grasslands is similar to the establishment, management, and use of nonmined grasslands.

As in the arid regions, pasture species must be selected that will accomplish the land use designated for the reclaimed land. These species must be adapted to the climate of the region and to the soil and other environmental factors of the site. These factors include the degree of salinity and sodicity of a site, the texture of the soil, and the steepness of the slope. Once the species selection has been made, the seeds can be drilled or broadcast at the appropriate season of the year—early spring or fall for cool-season grasses and late spring for the warm-season grasses. Even during the optimum season for seeding, plant establishment can fail due to inadequate moisture.

Although big advances have been made in the last 15 years in our understanding of the establishment and management of reclaimed pastures in the west, new information will continue to refine our present ideas and introduce new ideas. Since current reclamation practices require the replacement of topsoil and, in some cases, subsoil over spoil, pasture management problems are similar to those on nonmined land and much of the research on nonmined land should be applicable to mined land.

Cropland

The use of land reclaimed after mining for cropland is limited in the West primarily because of climatic conditions. Climatic and topographic conditions favorable for cropland are found almost exclusively in the Northern Great Plains. Cropland does exist in other western states, but often is irrigated and isolated from any of the present mining. In the Northern Great Plains, the majority of the cropland that occurs at mining sites is located in North Dakota and to a lesser extent in Montana. The crops grown are mainly small grains with some corn and sunflowers in western North Dakota.

Land reclaimed as cropland has been shown to be similar to unmined cropland. A reconstructed soil that contains the topsoil and possibly the subsoil of the original soil has essentially the same physical and chemical properties as the original soil. Nevertheless, much of the structure has been lost and some research data indicate that these reconstructed soils initially are more susceptible to erosion. A good practice is to seed newly reclaimed land into pasture for several years until some initial development of soil structure has occurred.

Proper planning for reclamation is necessary where the intended use of reclaimed land is cropland. Slopes that are too steep to safely operate farm machinery or where erosion is likely to quickly reduce the productivity of the reclaimed soil should not be considered for cropland. Reclamation can increase the overall suitability of an area for cropland by reducing slopes and adding topsoil to the higher areas of a landscape that formerly were knobs and eroded hilltops.

Some of the cropland in North Dakota has been designated as prime farmland. These areas of prime farmland are located in small tracts of 40 acres or less in well-drained toeslopes and swale positions of the landscape where they receive runon water. The greater depth of topsoil and subsoil on these prime soils was derived in part from the deposition of topsoil eroded from the surrounding hilltops and hillsides. Prime soils in North Dakota are commonly derived from the same material as adjacent nonprime land and are differentiated from the nonprime soils mainly by depth of topsoil and related parameters such as depth to carbonates. The higher productivity of prime soils results primarily from thicker topsoil and subsoil and additional runon water. Results of recent research suggests that the thickness of topsoil and subsoil available on these prime soils often exceeds that necessary for maximum crop production on these soils.

Currently, prime topsoils and subsoils are stripped, stockpiled, and replaced separately from nonprime topsoils and subsoils. Limited research on prime land in North Dakota suggests that overall productivity of the landscape could be improved and the productivity of the prime soils maintained by distributing the available topsoil and subsoil more uniformly throughout the landscape.

Reclamation of mined land can improve productivity over that of premine cropland and create productive cropland from land that what formerly was suitable only for rangeland or pasture. These possibilities exist where they are well planned as part of postmining land use goals.

BIBLIOGRAPHY

Aldon, Earl F. Vegetation parameters for judging the quality of reclamation on coal mine spoils in the Southwest. Great Basin Naturalist. 44:441-446; 1984.

Allen, E. B. The role of mycorrhizae in mined land diversity. In: Munshower, F. F.; Fisher, S. E., eds. 3rd biennial symposium on surface coal-mine reclamation in the Great Plains; 1984 March; Billings, MT. Bozeman, MT: Montana State University; 1984: 273-295.

Allaire, P. N. Bird species on mined lands: assessment and utilization in eastern Kentucky. IMMR 82/072. Lexington, KY: University of Kentucky, Institute of Mining and Minerals Research; 1980. 64 p.

Armiger, W. H.; Jones, J. N.; Bennett, O. L. Revegetation of land disturbed by strip mining of coal in Appalachia. ARS-NE-71. Beltsville, MD: U.S. Department of Agriculture, Agriculture Research Service; 1976. 38 p.

Ashby, W. C.; Kolar, C; Guerke, M. L.; Pursell, C. F.; Ashby, J. Our reclamation future the missing bet on trees. IIEQ Doc. 78/04. Chicago, IL: Illinois Institute for Environmental Quality; 1978. 99 p.

Ashby, W. C.; Vogel, W. G.; Rogers, N. F. Black Locust in the reclamation equation. Gen. Tech. Rep. NE-105. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1985. 12 p.

Barnhisel, R. I. Reclamation of surface mined coal spoils. EPA-600/7-77-093. Cincinnati, OH: U.S. Environmental Protection Agency, Research and Development; 1977. 57 p.

Beetle, A. A. A relict area on the Wyoming shortgrass plains. Journal of Range Management. 5:141-143; 1952.

Bennett, O. L.; Armiger, W. H.; Jones, J. N., Jr. Revegetation and use of eastern surface mine spoils. In: Land Application of waste materials. Ankeny, IA: Soil Conservation Society of America; 1976: 195-215.

Blauer, A. C.; Plummer, A. P.; McArthur, E. D.; Stevens, R.; Giunta, B. C. Characteristics and hybridization of important shrubs. 11. Chenopod family. Res. Pap. INT-177. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1976.

Bonham, Charles D.; Larson, Larry L.; Morrison, Ann. A survey of techniques for measurement of herbaceous and shrub production, cover, and diversity on coal lands in the West. Denver, CO: U.S. Department of the Interior, Office of Surface Mining, Region V. Contract No. J7090435; 1980. 79 p.

Boyce, S. G.; Merz, R. W. Tree species recommended for strip-mine plantations in western Kentucky. Tech. Pap. 160. Columbus, OH: U.S. Department of Agriculture, Forest Service, Central States Forest Experiment Station: 1959. 12 p.

Boyce, S. G.; Neebe, D. J. Trees for planting on strip-mined land in Illinois. Tech. Pap. 164. Columbus, OH: U.S. Department of Agriculture, Forest Service, Central States Forest Experiment Station; 1959. 33 p.

Branson, F. A.; Miller, R. F.; McQueen, I. S. Plant communities and soil moisture relationships near Denver, Colorado. Ecology. 46:311-319; 1965.

Branson, F. A.; Miller, R. F.; McQueen, I. S. Moisture relationships in twelve northern desert communities near Grand Junction, Colorado. Ecology. 57:1104-1124; 1976.

Brown, D. Handbook, equipment for reclaiming strip-mined land. Missoula, MT: U.S. Department of Agriculture, Forest Service, Equipment Development Center; 1977. 58 p.

Brown, D.; Hallman, R. G. Reclaiming disturbed lands. Missoula, MT: U.S. Department of Agriculture, Forest Service, Equipment Development Center; 1984. 91 p.

Brown, D. E. Great Basin conifer woodland. In: Brown, E. D., ed. Biotic communities of the Southwest United States and Mexico. Special Issue: Desert Plants 4(1-4):42-57; 1982a.

Brown, D. E. Great Basin montane scrubland. In: Brown, D. E., ed. Biotic communities of the Southwest United States and Mexico. Special Issue: Desert Plants 4(1-4):83-84; 1982b.

Brown, D. E. Plains and Great Basin grasslands. In: Brown, D. E., ed. Biotic communities of the Southwest United States and Mexico. Special Issue: Desert Plants 4(1-4):115-121; 1982c.

Brown, D. E. Semidesert grassland. In: Brown, D. E., ed. Biotic communities of the Southwest United States and Mexico. Special Issue: Desert Plants 4(1-4):123-131; 1982d.

Brown, Dorothy. Methods of surveying and measuring vegetation. Bull 42. Hurley, Berks, England: Commonwealth Bureau of Pastures and Field Crops; 1954. 223 p.

Brown, J. H. Use of trees for revegetation of surface-mined areas. In: Bondurant, D. M., ed. Proceedings, revegetation and economic use of surface-mined land and mine refuse symposium. 1971 December 2-4; Pipestem State Park, WV. Morgantown, WV: West Virginia University; 1971: 26-28.

Brown, R. W. Distribution of plant communities in southeastern Montana badlands. American Midland Nationalist. 85:458-477; 1971.

Brown, R. W.; Asay, K. H.; Frischknecht, N. C.; Hodder, R. L. Species selection. Chapter 2. In: User guide to vegetation. Gen. Tech. Rep. INT-64. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979: 13-18.

Burton, J. C. Methods of inoculating seeds and their effect on survival of rhizobia. In: Nutman, P. S., ed. Symbiotic nitrogen fixation in plants. International Biological Program. Vol. 7. London: Cambridge University Press; 1975: 175-188.

Camin, K. Q.; Hardy, R. G. Mined-land redevelopment: Southeast Kansas portion of the Ozarks region. Final report prepared for the Ozarks Regional Commission. TA70-19(NEG). Lawrence, KS: State Geology Survey; 1972. 173 p.

Carpenter, Stanley B., ed. Symposium on surface mining hydrology, sedimentology, and reclamation. Proceedings of the symposium; 1979 December 4-7; Lexington, KY. UKY BU119. Lexington, KY: University of Kentucky, College of Engineering; 1979. 353 p.

Chambers, Jeanne C.; Brown, Ray W. Methods for vegetation sampling and analysis on revegetated mined lands. Gen. Tech. Rep. INT-151. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983. 57 p.

Christensen, E. M. The foothill bunchgrass vegetation of central Utah. Ecology. 44:156-158; 1963.

Clark, F. B. Forest planting on strip-mined land in Kansas, Missouri, and Oklahoma. Tech. Pap. 141. Columbus, OH: U.S. Department of Agriculture Forest Service, Central States Forest Experiment Station; 1954. 33 p.

Colman, E. A. Vegetation and watershed management. New York, NY: Ronald Press; 1953. 412 p.

Commonwealth of Kentucky. A manual on Kentucky reclamation. Frankfort, KY: Kentucky Department of Natural Resources and Environmental Protection; 1976.

Cook, C. Wayne; Bonham, Charles D. Techniques for vegetation measurements and analysis for pre- and post-mining inventory. Range Sci. Ser. No. 28. Fort Collins, CO: Colorado State University, Department of Range Science; 1977. 94 p.

Costello, D. F. Important species of the major forage types in Colorado and Wyoming. Ecological Monographs. 14:107-134; 1944.

Court, A. The climate of the conterminous United States. In: Bryson, R. E.; Hare, F. K., ed. World survey of climatology. Vol. 11. Climates of North America. Amsterdam: Elsevier Science Publishing Co.; 1974: 13-18.

Currier, W. F.; Merkel, D. L. Critical area stabilization workship. Las Cruces, NM: U.S. Department of Agriculture, Agriculture Research Service; 1971. 197 p.

Czapowskyj, M. M. Experimental planting of 14 tree species on Pennsylvania's anthracite strip-mine spoils. Res. Pap. NE-155. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1970. 20 p.

Daniel, T. W.; Helms, J. A.; Baker, F. S. Principles of silviculture. 2nd ed. New York: McGraw-Hill Co.; 1979.

Daniels, W. L.; Burger, J. A.; Amos, D. T. The effect of controlled overburden placement on mine soil properties and the growth of loblolly pine. Final Rep. OSM Contract T5120114. Blacksburg, VA: Virginia Polytechnical Institute and State University, Department of Agronomy and Forestry; 1984. 72 p.

Davis, G; Hutnik, R. J., eds. Ecology and reclamation of devastated land. Vols. 1 and 2. New York: Gordon and Breach; 1973.

DePuit, E. J.; Coenenberg, J. G. Responses of revegetated coal strip mine spoils to variable fertilization rates, longevity of fertilization program, and season of seeding. Res. Rep. 150. Bozeman, MT: Montana Agriculture Experiment Station; 1979.

DePuit, E. J.; Coenenberg, J. G.; Skilbred, C. L. Establishment of diverse native plant communities on coal surface-mined lands in Montana as influenced by seeding method, mixture, and rate. Res. Rep. 163. Bozeman, MT: Montana Agriculture Experiment Station; 1980.

Despain, D. G. Vegetation of the Big Horn Mountains, Wyoming, in relation to substrate and climate. Ecological Monographs. 43:329-355; 1973.

Dickson, Kenneth L; Vance, Devain. Revegetating surface mined lands for wildlife in Texas and Oklahoma. FWS/OBS-81/25. Kearneysville, WV: U.S. Department of the Interior, Fish and Wildlife Service, Office of Biological Services, Eastern Energy and Land Use Team; 1981. 121 p.

Evangelou, V. P.; Grove, J. H. Salts in eastern U.S. coal spoils. Reclamation News and Views, Vol. 1, No. 5. Lexington, KY: University of Kentucky, College of Agriculture; 1982.

Farmer, Robert E., Jr.; Rennie, John C.; Scanlon, David H., III; Zarger, Thomas G. Technical guides on use of reference areas and technical standards for evaluating surface mine vegetation. Knoxville, TN: U.S. Department of the Interior, Office of Surface Mining, Region II. Contract OSM J5701442/TV-54055A; 1981. 82 p.

Finn, R. F. Ten years of strip-mine research in Ohio. Tech. Pap. 153. Columbus, OH: U.S. Department of Agriculture, Forest Service, Central States Forest Experiment Station; 1958. 38 p.

Foster, C. A.; Henry, D. S. Sixteen years' evolution of woody plants on surface mines in eastern Kentucky. Meeting of southern section, Soil Conservation Society of America; 1985 February 4; Biloxi, MS. Ankeny, IA: Soil Conservation Society of America; 1985. 11 p.

Fowells, H. A., compiler. Silvics of forest trees of the United States. Agric. Handb. No. 271. Washington, DC: U.S. Department of Agriculture; 1965. 762 p.

Fowler, D. K; Adkisson, L. F. Survival and growth of wildlife shrubs and trees on acid mine spoil. Tech Note B37. Norris, TN: Tennessee Valley Authority, Division of

Land and Forest Resources; 1980. 49 p.
Fribourg, H. A.; Jent, C. H.; Maher, S.; Burns, J. D.; Paugh, J. H. Guide to revegetating surface coal-mined areas in Tennessee. SP 248. Knoxville, TN: University of Tennessee, Institute of Agriculture; 1981. 26 p.

Garner, R. V. Revegetation of strip-mined areas in Oklahoma. Proceedings of Oklahoma Academy of Science. 34:208-209; 1953.
Geyer, W. A. Tree species performance on Kansas coal spoils. In: Hutnik, R. J.; Davis, G., eds. Ecology and reclamation of devastated land. Vol. 2. New York: Gordon and Breach; 1973: 81-90.
Gill, J. D.; Healy, W. M. Shrubs and vines for Northeastern wildlife. Gen. Tech. Rep. NE-9. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1974. 180 p.
Goodall, D. W. Some consideration in the use of point-quadrats for the analysis of vegetation. Australian Journal of Scientific Research, Ser. B5; 1952: 1-41.
Grandt, A. F.; Lang, A. L. Reclaiming Illinois strip coal land with legumes and grasses. Univ. Bull. 628. Urbana, IL: University of Illinois Agricultural Experiment Station: 1958. 64 p.
Graves, D. H., ed. Symposium on surface mining hydrology, sedimentology, and reclamation. Proceedings of the symposium; 1980 December 1-5; Lexington, KY. UKY BU123. Lexington, KY: University of Kentucky, College of Engineering; 1980. 480 p.
Graves, D. H., ed. Symposium on surface mining hydrology, sedimentology, and reclamation. Proceedings of the symposium; 1981 December 7-11; Lexington, KY. UKY BU126. Lexington, KY: University of Kentucky, College of Engineering; 1981. 558 p.
Graves, D. H., ed. Symposium on surface mining, hydrology, sedimentology, and reclamation. Proceedings of the symposium; 1982 December 6-10; Lexington, KY. UKY BU129. Lexington, KY: University of Kentucky, College of Engineering; 1982. 728 p.
Graves, D. H., ed. Symposium on surface mining, hydrology, sedimentology, and reclamation. Proceedings of the symposium; 1983 November 28-December 2; Lexington, KY. UKY BU133. Lexington, KY: University of Kentucky, College of Engineering; 1983. 554 p.
Graves, D. H., ed. Symposium on surface mining, hydrology, sedimentology, and reclamation. Proceedings of the symposium; 1984 December 2-7; Lexington, KY. UKY BU136. Lexington, KY: University of Kentucky, College of Engineering; 1984. 492 p.
Graves, D. H., ed. Symposium on surface mining, hydrology, sedimentology, and reclamation. Proceedings of the symposium; 1985 December 9-13; Lexington, KY. UKY BU139. Lexington, KY: University of Kentucky, College of Engineering; 1985. 439 p.
Graves, D. H., ed. Symposium on surface mining, hydrology, sedimentology, and reclamation. Proceedings of the symposium; 1986 December 8-11; Lexington, KY. UKY BU142. Lexington, KY: University of Kentucky, College of Engineering; 1986. 283 p.

Hanson, H. C. Characteristics of the Stipa comata-Bouteloua curtipendula associations of Northern Colorado. Ecology. 36:269-280; 1955.
Hanson, H. C.; Whitman, W. Characteristics of major grassland types in western North Dakota. Ecological Monographs. 8:57-114; 1938.
Harrington, H. D. Manual of the plants of Colorado. Chicago, IL: Sage Books, Swallo Press Inc.; 1964. 666 p.
Hart, G.; Byrnes, W. R. Trees for strip-mined lands. Stn. Pap. 136. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1960. 36 p.
Hitchcock, A. S. Manual of the grasses of the United States. 2nd ed. Misc. Publ. 200. Washington, DC: U.S. Department of Agriculture; 1950. 1051 p.
Hoffman, G. R.; Alexander, R. R. Forest vegetation of the Big Horn Mountains, Wyoming: A habitat type classification. Res. Pap. RM-170. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1976. 38 p.
Hughes, H. D.; Heath, M. E.; Metcalfe, D. S. Forages, 2nd ed. Ames, IA: Iowa State University Press; 1969. 707 p.
Hunt, Charles B. Natural regions of the United States and Canada. San Francisco: W. H. Freeman and Co.; 1974. 725 p.

Ibrahim, K. M.; West, N. E.; Goodwin, D. L. Phytosociological characteristics of perennial Atriplex-dominated vegetation of southeastern Utah. Vegetatio. 24:13-22; 1972.
Institute for Land Rehabilitation. Selection, propagation and field establishment of native plant species on disturbed arid lands. Bull. 500. Logan, UT: Utah Agriculture Experiment Station; 1979. 49 p.
Iowa Land Rehabilitation Advisory Board. Recommendations for establishment of vegetation on surface mined areas. Des Moines, IA: Iowa Land Rehabilitation Advisory Board, Department of Soil Conservation; 1973. 20 p.

Jameson, D. A.; Reid, E. H. The pinyon-juniper type of Arizona. Journal of Range Management. 18:152-153; 1965.

Knight, D. H. Methods for sampling vegetation. An instruction manual. Laramie, WY: University of Wyoming, Department of Botany, Ark Industries; 1978. 87 p.
Kuchler, A. W. Potential vegetation of the conterminous United States. Spec. Publ. 38. New York, NY: American Geographical Society; 1964. 115 p.

Larson, J. E. Revegetation equipment catalog. Missoula, MT: U.S. Department of Agriculture, Forest Service, Equipment Development Center; 1980. 198 p.
Larson, J.; Melodragovich, E. Catalog for hand planting tools. Missoula, MT: U.S. Department of Agriculture, Forest Service, Missoula Equipment Development Center; 1982. 33 p.
Larson, Larry L. The concept of species diversity in the evaluation of revegetation success. Denver, CO: U.S. Department of the Interior, Office of Surface Mining, Region V. 1980. 13 p.
Limstrom, G. A. Forestation of strip-mined land in the

Central States. Agric. Handb. 166. Washington, DC: U. S. Department of Agriculture; 1960. 74 p.
Long, S. G. Characteristics of plants used in western reclamation. 2nd ed. Fort Collins, CO: Environment Research and Technology, Inc.; 1981. 138 p.
Lowry, G. L; Antalosky, M. T. Extent and reclamation status of Texas lignite strip-mines. In: Proceedings, 3rd annual meeting of the Canadian Land Reclamation Association. 1978 May 29-June 1; Sudbury, Ontario. Guelph, Ontario: Canadian Land Reclamation Association; 1978: 184-191.
Lyle, E. S., Jr. Grass, legume, and tree establishment on Alabama coal surface mines. In: Utz, K. A., ed. Proceedings of the conference on forestation of disturbed surface areas; 1976 April 14-15; Birmingham, AL. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southeastern Area State and Private Forestry and International Forest Seed Company; 1976: 12-19.
Lyle, E. S., Jr. Surface mine reclamation manual. New York: Elsevier Science Publishing Co.; 1986. 300 p.

Marquiss, R.; Lang, R. Vegetational composition and ground cover of two natural relict areas and their associated grazed areas in the Red Desert of Wyoming. Journal of Range Management. 12:104-109; 1959.
Marr, J. W. Ecosystems of the East Slope of the Front Range in Colorado. Ser. in Biol. No. 8. Boulder, CO: University of Colorado Press; 1967. 134 p.
Mason, L. R.; Andrews, H. M.; Carley, J. A.; Haacke, E. D. Vegetation and soils of No Man's Land Mesa relict area, Utah. Journal of Range Management. 20:45-49; 1967.
McArthur, E. D. Shrub selection and adaptation for rehabilitation plantings. In: Shrub establishment on disturbed arid and semi-arid lands. Laramie, WY: Wyoming Fish and Game Department; 1981: 1-8.
McArthur, E. D.; Blauer, A. C.; Plummer, A. P.; Stevens, R. Characteristics and hybridization of important intermountain shrubs III. Sunflower family. Res. Pap. INT-220. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979. 82 p.
McCart, G. D. Guidelines for reclamation and revegetation, surface mined areas in southwest Virginia. Blacksburg, VA: Virginia Polytechnical Institute and State University, Extension Division; 1973. 44 p.
McKell, C. M.; Briede, J.; Pendleton, S. Selection of plant materials for the Southwest. In: Aldon, E. F.; Oaks, W. R., ed. Reclamation of mined lands in the Southwest. Albuquerque, NM: U.S. Department of Agriculture, Soil Conservation Service, Forest Service Western Regional Coordination Committee; 1982. 21 p.
Medvick, C. Selecting plant species for revegetating surface coal mined lands in Indiana—a forty year record. In: Hutnik, R. J.; Davis, G., eds. Ecology and reclamation of devastated land. Vol. 2. New York: Gordon and Breach; 1973: 65-80.
Miles, V. C.; Ruble, R. W.; Bond, R. L. Performance of plants in relation to spoil classification in Pennsylvania. In: Hutnik, R. J.; Davis, G., eds. Ecology and reclamation of devastated land. Vol. 2. New York: Gordon and Breach; 1973: 13-31.
Moir, W. H. Steepe communities in the foothills of the Colorado Front Range and their relative productivities. American Midland Nationalist. 81:331-340; 1969.
Moir, W. H.; Ludwig, J. A. A classification of the spruce-fir and mixed conifer habitat types of Arizona and New Mexico. Res. Pap. RM-207. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1979. 47 p.
Monsen, S. B.; Plummer, A. P. Plants and treatments for revegetation of disturbed sites in the Intermountain area. In: Wright, R. A., ed. The reclamation of disturbed arid lands. Albuquerque, NM: University of New Mexico Press; 1978: 155-173.
Morris, Meredith J. Estimating understory plant cover with rated microplots. Res. Pap. RM-104. Fort Collins, CO; U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1973. 12 p.
Mueller-Dombois, D.; Ellenberg, H. Aims and methods of vegetation ecology. New York: John Wiley and Sons; 1974. 547 p.

Narten, P. F.; Litner, S. T.; Allingham, J. W.; Foster, L.; Larsen, D. M.; McWreath, H. C., III. Reclamation of mined lands in the western coal region. Geol. Surv. Circ. 872. Alexandria, VA: U.S. Department of the Interior; 1983. 56 p.
Neumann, U. Succession of soil fauna in afforested spoil banks of the brown-coal mining district of Cologne. In: Hutnik, R. J.; Davis, G., eds. Ecology and reclamation of devastated land. Vol. 1. New York: Gordon and Breach; 1973: 335-348.
Nixon, E. S. A comparative study of the mountain brush vegetation in Utah. Great Basin Nationalist. 27:59-66; 1967.

Oaks, W. R. Reclamation and seeding of plant materials for reclamation. In: Aldon. E. F.; Oaks, W. R., eds. Reclamation of mined lands in the Southwest. Albuquerque, NM: U.S. Department of Agriculture, Soil Conservation Service, Forest Service Western Regional Coordinating Committee. 21:145-150; 1982.
Oosting, H. J.; Reed, J. F. Virgin spruce-fir forest in the Medicine Bow Mountains, Wyoming. Ecological Monographs. 22:26-91; 1952.

Packer, P. E.; Aldon, E. F. Revegetation techniques for dry regions. In: Schaller, F. W.; Sutton, P., eds. Reclamation of drastically disturbed lands: proceedings of a symposium; 1976 August 9-12; Wooster, OH. Madison, WI: American Society of Agronomy; 1978: 425-450.
Packer, P. E.; Jensen, C. E.; Noble, E. L.; Marshall, J. A. Models to estimate revegetation potentials of land surface-mined for coal in the West. Gen. Tech. Rep. INT-123. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 25 p.
Pase, Charles P. Community structure analysis—a rapid, effective range condition estimation for semi-arid ranges. In: Arid land resource inventories: developing cost-efficient methods: an international workshop; 1980 November 30-December 6; La Paz, Mexico. Gen.

Tech. Rep. WO-28. Washington, DC: U.S. Department of Agriculture, Forest Service; 1981: 425-430.

Paton, R. R.; Deane, James A.; Kohl, Eddie; Krause, Rodney R.; Richter, Donald E.; Soine, George. Tree planting guide for the reclamation of strip mine lands in Ohio. Tech. Bull. 70-1. Cambridge, OH: Ohio Reclamation Association; 1970. 14 p.

Pearson, R. W.; Adams, F., eds. Soil acidity and liming. Agron. Ser. 12. Madison, WI: American Society of Agronomy; 1967. 274 p.

Pfister, R. D.; Kovalchik, Arno, S. F.; Presby, R. C. Forest habitat types of Montana. Gen. Tech. Rep. INT-34. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1977. 174 p.

Pieper, R. D. Measurement techniques for herbaceous and shrubby vegetation. Las Cruces, NM: New Mexico State University, Department of Animal, Range, and Wildlife Sciences; 1973. 187 p.

Plass, W. T. An evaluation of trees and shrubs for planting surface-mine spoils. Res. Pap. NE-317. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1975. 8 p.

Plass, W. T. Direct seeding of trees and shrubs on surface-mined lands in West Virginia. In: Utz, K. A., ed. Proceedings of the conference on forestation of disturbed surface areas; 1976 April 14-15; Birmingham, AL. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southeastern Area State and Private Forestry and International Forest Seed Company; 1976: 32-42.

Plass, W. T. Growth and survival of hardwoods and pine interplanted with European alder. Res. Pap. NE-376. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1977. 10 p.

Plass, W. T. Reclamation of coal-mined land in Appalachia. Journal of Soil and Water Conservation. 33(2):56-61; 1978.

Plass, W. T. Use of mulches and soil stabilizers for land reclamation in the eastern United States. In: Schaller, Frank W.; Sutton, Paul, eds. Reclamation of drastically disturbed lands. Madison, WI: American Society of Agronomy; 1978: 329-337.

Plummer, A. P. Revegetation of disturbed intermountain area sites. In: Thames, J. L., ed. Reclamation and use of disturbed land in the Southwest. Tucson, AZ: University of Arizona Press; 1977: 302-339.

Plummer, A. P.; Christensen, D. R.; Monsen, S. B. Restoring big game range in Utah. Publ. 68-3. Salt Lake City, UT: Utah Division of Fish and Game; 1968. 183 p.

Potter, H. S.; Weitzman, S.; Trimble, G. R., Jr. Reforestation of strip-mined lands in West Virginia. Stn. Pap. 43. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1951. 28 p.

Powell, J. L.; Barnhisel, R. I.; Akin, G. W.; Ebelhar, M. W. The state of the art of reclaiming land surface-mined for coal in the western Kentucky coal field. In: Proceedings, 5th symposium on surface mining and reclamation. 1977 October 18-20; Louisville, KY. Washington, DC: National Coal Association; 1977: 225-273.

Quinnild, C. L.; Cosby, H. E. Relicts of climax vegetation on two mesas in western North Dakota. Ecology. 39:29-32; 1958.

Raelson, J. V.; McKee, G. W. Measurement of plant cover to evaluate revegetation success. Agron. Ser. 67. University Park, PA: Pennsylvania State University, Department of Agronomy; 1982. 45 p.

Rafaill, B. L.; Vogel, W. G. A guide for vegetating surface-mined lands for wildlife in eastern Kentucky and West Virginia. FWS/OBS-78/84. Harpers Ferry, WV: U.S. Department of the Interior, Fish and Wildlife Service, Office of Biological Services; 1978. 89 p.

Rawson, J. R. Surface mining and wildlife. In: Bondurant, D. M., ed. Proceedings, revegetation and economic use of surface-mined land and mine refuses symposium. 1971 December 2-4; Pipestem State Park, WV. Morgantown, WV: West Virginia University; 1971: 37-39.

Research Committee on Coal Mine Spoil Revegetation in Pennsylvania. A guide for revegetating bituminous strip-mine spoils in Pennsylvania. (rev.) Harrisburg, PA: Research Committee on Coal Mine Spoil Revegetation in Pennsylvania; 1971. 46 p.

Ries, R. E.; Day, A. D. Use of irrigation in reclamation in dry regions. In: Schaller, F. W.; Sutton, P., eds. Reclamation of drastically disturbed lands: proceedings of a symposium; 1976 August 9-12; Wooster, OH. Madison, WI: American Society of Agronomy; 1978: 505-520.

Ries, R. E.; Hofmann, L. Pasture and hayland: measures of reclamation success. In: Munshower, F. F.; Fisher, S. E., eds. 3rd biennial symposium on surface coal-mine reclamation in the Great Plains; 1984 March; Billings, MT. Bozeman, MT: Montana State University; 1984: 307-317.

Riley, C. V. Reclamation of coal strip-mined lands with reference to wildlife plantings. Journal of Wildlife Management. 21(4):402-413; 1957.

Robertson, D. R.; Nielson, J. L.; Bare, N. H. Vegetation and soils of alkali sagebrush and adjacent big sagebrush ranges in North Park, Colorado. Journal of Range Management. 19:17-20; 1966.

Rogers, N. F. Strip-mined lands of the Western Interior Coal Province. Bull. 475. Columbia, MO: University of Missouri, College of Agriculture Resources; 1951. 55 p.

Ruffner, J. D.; Steiner, W. W. Evaluation of plants for use on critical sites. In: Hutnik, R. J.; Davis, G., eds. Ecology and reclamation of devastated land. Vol. 2. New York: Gordon and Breach; 1973: 3-12.

Rumbaugh, M. D.; Johnson, D. A.; van Epps, G. A. Forage diversity increases yield and quality. Utah Science. 42:114-117; 1981.

Schaller, F. W.; Sutton, P., eds. Reclamation of drastically disturbed lands. Madison, WI: American Society of Agronomy; 1978. 742 p.

Schopmeyer, S. C., tech. coord. Seeds of woody plants in the United States. Agric. Handb. 450. Washington, DC: U.S. Department of Agriculture; 1974. 883 p.

Sharp, W. C. Conservation plants for the Northeast. Program Aid 1154. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service; 1977. 40 p.

Slick, B. M.; Curtis, W. R. A guide for the use of organic materials as mulches in reclamation of coal minesoils in the Eastern United States. Gen. Tech. Rep. NE-98. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1985. 144 p.

Smith, R. M.; Sobek, A. A.; Arkle, T., Jr; Sencindiver, J. C.; Freeman, J. R. Extensive overburden potentials for soil and water quality. EPA-600/2-76-184. Cincinnati, OH: U.S. Environmental Protection Agency, Office of Research and Development; 1976. 311 p.

Shiue, C. Systematic sampling with multiple random starts. Forest Science. 6:42-50; 1960.

Sobek, A. A.; Schuller, W. A.; Freeman, J. R.; Smith, R. M. Field and laboratory methods applicable to overburden and minesoils. EPA-600/2-78-054. Cincinnati, OH: U.S. Environmental Protection Agency, Industrial Environmental Research Laboratory; 1978. 204 p.

Sopper, W. E.; Kerr, S. N., eds. Utilization of municipal sewage effluent and sludge on forest and disturbed land. University Park, PA: Pennsylvania State University Press; 1979. 537 p.

Steele, R.; Cooper, S. V.; Ondov, D. M.; Roberts, D. W.; Pfister, R. D. Forest habitat types of eastern Idaho-western Wyoming. Gen. Tech. Rep. INT-144. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1983.

Steffurad, A. Grass. The yearbook of agriculture. Washington, DC: U.S. Department of Agriculture; 1948. 892 p.

Steffurad, A. Pasture and range plants. Bartlesville, OK: Phillips Petroleum Co.; 1963. 176 p.

Stubbendieck, J.; Hatch, S. L.; Kjar, K. J. North American range plants. Lincoln, NB: Natural Resources Enterprises, Inc.; 1981.

Terrell, E. E. A checklist of names for 3,000 vascular plants of economic importance. Agric. Handb. 505. Washington, DC: U.S. Department of Agriculture; 1977. 201 p.

Thames, J. L., ed. Reclamation and use of disturbed lands in the Southwest. Tuscon, AZ: University of Arizona Press; 1977.

Thilenius, J. F. Classification of deer habitat in the pondersoa pine forest of the Black Hills, South Dakota. Res. Pap. RM-91. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1972. 28 p.

Thompson, R. L.; Vogel, W. G.; Taylor, D. D. Vegetation and flora of a coal surface-mined area in Laurel County, Kentucky. Castanea. 49:111-126; 1984.

Thornburg, A. A. Plant materials for use on surface-mined lands in arid and semiarid regions. SCS-TP-157. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service; 1982. 88 p.

Thornburg, A. A.; Fuchs, S. H. Plant materials and requirements for growth in dry regions. In: Schaller, F. W.; Sutton, P., eds. Reclamation of drastically disturbed lands: proceedings of a symposium; 1976 August 9-12; Wooster, OH. Madison, WI: American Society of Agronomy; 1978: 411-423.

Thornthwaite, C. W. An approach toward a rational classification of climate. Geographical Review. 38:55-94; 1948.

Turner, R. M. Great Basin desertscrub. In: Brown, D. E., ed. Biotic communities of the Southwest United States and Mexico. Special Issue: Desert Plants 4(1-4):145-154; 1982.

Tyner, E. H.; Smith, R. M. The reclamation of the strip-mined coal lands of West Virginia with forage species. Soil Science Society of American Proceedings. 10:429-436; 1945.

U.S. Department of Agriculture, Forest Service. Range plant handbook. Washington, DC: U.S. Department of Agriculture, Forest Service; 1937.

U.S. Department of Agriculture, Forest Service. Techniques and methods of measuring understory vegetation. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station and Asheville, NC: Southeastern Forest Experiment Station; 1959. 174 p.

U.S. Department of Agriculture, Forest Service. User guide to soils: mining and reclamation in the West. Gen. Tech. Rep. INT-68. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979. 80 p.

U.S. Department of Agriculture, Forest Service. User guide to vegetation: mining and reclamation in the West. Gen. Tech. Rep. INT-64. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979. 85 p.

U.S. Department of Agriculture, Forest Service. Wildlife: user guide for mining and reclamation. Gen. Tech. Rep. INT-126. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 77 p.

U.S. Department of Agriculture, Soil Conservation Service. Guide for the revegetation of surface mine spoil. Morgantown, WV: U.S. Department of Agriculture, Soil Conservation Service; 1969. 6 p.

U.S. Department of Agriculture, Soil Conservation Service. Plant performance on surface coal mine spoil in eastern United States. SCS-TP-155. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service; 1978. 76 p.

U.S. Department of Agriculture, Soil Conservation Service. Mine soil classification and use. A Kentucky guide for vegetative treatment. Lexington, Ky: U.S. Department of Agriculture, Soil Conservation Service; 1980. 41 p.

U.S. Department of Agriculture, Soil Conservation Service. Soil survey of White and VanBuren Counties, Tennessee. 1981-226-006/51. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service; 1981. 86 p.

U.S. Department of Agriculture, Soil Conservation Service. Guidelines for establishing vegetation on surface mined lands. Prepared for Texas Railroad Commission Surface Mining and Reclamation Division. Temple, TX: U.S. Department of Agriculture, Soil Conservation Service; 1981. 21 p. and Appendixes.

U.S. Department of Agriculture, Soil Conservation Service. State standard and specifications for critical area treatment. Stillwater, OK: U.S. Department of Agriculture, Soil Conservation Service; 1983. 13 p.

U.S. Department of Agriculture, Soil Conservation Service.

State standards and specifications for tree planting. Stillwater, OK: U.S. Department of Agriculture, Soil Conservation Service; 1982. 5 p.
U.S. Department of Agriculture, Soil Conservation Service. Missouri standard and specification for critical area planting. Columbus, MO: U.S. Department of Agriculture, Soil Conservation Service; 1978. 21 p.
U.S. Department of Agriculture, Soil Conservation Service. Critical area planting for reconstructed mined land. TG Notice KS-69. Salina, KS: U.S. Department of Agriculture, Soil Conservation Service; 1980. 9 p.
U.S. Department of Agriculture, Soil Conservation Service. Land reconstruction, currently mined land. TGH Notice 25. Alexandria, LA: U.S. Department of Agriculture, Soil Conservation Service; 1983. 6 p.
U.S. Department of Commerce. Weather atlas of the United States. Detroit, MI: Gale Research Co.; 1975. 282 p.
U.S. Water Resources Council. The Nation's water resources. Washington, DC: Water Resources Council; 1968.

Van Dyne, George M.; Vogel, Willis G.; Fisser, Herbert G. Influence of plot size and shape on range herbage production estimates. Ecology. 44:746-759; 1963.
Veith, D. L.; Bickel, K. L.; Hopper, R. W. E.; Norland, M. R. Literature on the revegetation of coal-mined lands: an annotated bibliography. Inf. Circ. 9048. Washington, DC: U.S. Department of the Interior, Bureau of Mines; 1985. 296 p.
Vierts, Steven R. A new instrument for measuring ground cover based on the point-hit technique—the optical point bar. In: 2nd annual meeting, American Society for Surface Mining and Reclamation; 1985 October 8-10; Denver, CO. Princeton, WV: American Society for Surface Mining and Reclamation; 1985: 106-109.
Vimmerstedt, J. P.; Finney, J. H. Importance of earthworm introduction on litter burial and nutrient distribution in Ohio strip-mine spoil banks. Soil Science Society of America Proceedings. 37:388-391; 1973.
Vogel, W. G.; Berg, W. A. Grasses and legumes for cover on acid strip-mine spoils. Journal of Soil and Water Conservation. 23(3):89-91; 1968.
Vogel, W. G. All season seeding of herbaceous vegetation for cover on Appalachian strip-mine spoils. In: Proceedings, 2nd research and applied technology symposium on mined-land reclamation; 1974 October 22-24; Louisville, Ky. Washington, DC: National Coal Association; 1974: 175-180.
Vogel, W. G. Requirements and use of fertilizer, lime, and mulch for vegetating acid mine spoil. In: Proceedings, 3rd symposium on surface mining and reclamation, Vol. II; 1975 October 21-23; Louisville, KY. Washington, DC: National Coal Association; 1975: 152-170.
Vogel, W. G. Revegetation of surface-mined land in the East. In: Proceedings 1977 annual meeting of the Society for American Foresters; 1977 October 2-5; Albuquerque, NM. Washington, DC: Society of American Foresters; 1978: 167-172.
Vogel, W. G. A guide for revegetating coal minesoils in the Eastern United States. Gen. Tech. Rep. NE-68. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1981. 190 p.
Vogel, W. G. Planting and species selection for revegetation of abandoned acid spoils. In: Proceedings, conference on reclamation of abandoned acid spoils; 1984 September 12-13; Osage Beach, MO. Jefferson City, MO: Missouri Department of Natural Resources, Land Reclamation Commission; 1984: 70-83.
Vories, A. C., ed. Reclamation of western surface mined lands. Fort Collins, CO: Ecology Consultants Incorporated; 1976.

Wade, G. L.; Thompson, R. L.; Vogel, W. G. Success of trees and shrubs in an 18-year-old planting on mine spoil. Res. Pap. NE-567. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1985. 10 p.
Wade, G. L.; Crews, J. T.; Vogel, W. G. Development and productivity of forest plantations on a surface mine in southeastern Kentucky. In: Proceedings, better reclamation with trees conference; 1985 June 5-7; Carbondale, IL. Carbondale, IL: Southern Illinois University; 1986. 10 p.
Wali, M. K., ed. Ecology and coal resource development. Vols. 1 and 2. New York: Pergamon Press; 1979. 1091 p.
Wasser, C. H. Ecology and culture of selected species useful in revegetating disturbed lands in the West. FWS/OBS-82/56. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service, Office of Biological Services; 1982. 347 p.
Wendt, G. W., ed. Symposium on the reclamation of lands disturbed by surface mining: a cornerstone for communication and understanding. 1984 national meeting, American Society for Surface Mining and Reclamation; 1984 July 10-13; Owensboro, KY. Middlesex, England: Science Reviews Limited; 1985. 461 p.
West, N. E. Shrublands of Utah. Utah Science. 35:4-6; 1974.
West, N. E. Great Basin-Colorado Plateau sagebrush semidesert. In: West, N. E., ed. Ecosystems of the world. Vol. 5. Temperate deserts and semi-deserts. Amsterdam: Elsevier Science Publishing Co.; 1983a: 331-349.
West, N. E. Western Intermountain sagebrush steppe. In: West, N. E., ed. Ecosystems of the world. Vol. 5. Temperate deserts and semi-deserts. Amsterdam: Elsevier Science Publishing Co.; 1983b: 351-374.
West, N. E. Intermountain salt-desert shrubland. In: West, N. E., ed. Ecosystems of the world. Vol. 5. Temperate deserts and semi-deserts. Amsterdam: Elsevier Science Publishing Co.; 1983c: 375-397.
West, N. E. Colorado Plateau-Mohavian blackbrush semidesert. In: West, N. E., ed. Ecosystems of the world. Vol. 5. Temperate deserts and semi-deserts. Amsterdam: Elsevier Science Publishing Co.; 1983d: 399-411.
West, N. E.; Ibrahim, K. I. Soil-vegetation relationships in the shadscale zone of southern Utah. Ecology. 49: 445-456; 1968.
Williams, Dean; Fisher, Scott E., Jr. Bridging the gap between better science, regulation, and the surface mining operation. 2nd annual meeting, American Society for Suface Mining and Reclamation; 1985 October 8-10; Denver, CO. Princeton, WV: American Society for Surface Mining and Reclamation: 1985. 412 p.
Wilsie, C. P. Crop adaptations and distribution. San Fran-

cisco: W. H. Freeman Co.; 1962.
Wilson, H. A. The microbiology of strip-mine spoil. Bull. 506T. Morgantown, WV: West Virginia University, Agricultural Experiment Station; 1965. 44 p.
Winkwerth, R. D.; Goodall, D. W. A cross wire sighting tube for point-quadrat analysis. Ecology. 43:342-343; 1962.
Wischmeier, Walter H.; Smith, Dwight D. Predicting rainfall erosion losses—A guide to conservation planning. Agric. Handb. 537. Washington, DC: U.S. Department of Agriculture; 1978. 58 p.
Woodin, H. E.; Lindsey, A. A. Juniper-pinyon east of the Continental Divide, as analyzed by the line-strip method. Ecology. 35:473-489; 1954.
Wright, J. C.; Wright, E. A. Grassland types of south central Montana. Ecology. 29:449-460; 1948.
Wright, R. A., ed. Reclamation of disturbed arid lands. Albuquerque, NM: University of New Mexico Press; 1978.

Zarger, T. G.; Curry, J. A.; Allen, J. C. Seeding of pine on coal spoils in the Tennessee Valley. In: Hutnik, R. J.; Davis, G., eds. Ecology and reclamation of devastated land. Vol. 1. New York: Gordon and Breach; 1973: 509-524.

This page intentionally left blank.