RECLAMATION OF SURFACE–MINED LAND[1, 2]

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ABSTRACT

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Technology relating to the revegetation of lands disturbed by surface-mining is well advanced in the midwestern and Appalachian coal fields. Past accomplishments demonstrate that the disturbances resulting from surface-mining have a potential for management and development. The challenge for the future will be to develop this potential and to maximize the productivity of reclaimed land. Basic to this concept is the development of practical methods for pre-mining and post-mining evaluation. Chemical and physical characteristics of the overburden need to be characterized to plan an efficient and profitable mining operation that complements a reclamation program designed to achieve an appropriate land-management objective. This will return an increasingly larger percentage of the land disturbed by surface-mining for coal to economic use.

New technology for the reclamation and revegetation of lands disturbed by surface-mining for coal is developing at a rapid rate. This trend will continue as funds for environmental research increase and as more emphasis is placed on environmental protection and land-use planning. The expanding research program has encouraged participation by scientists trained in many disciplines that are directly or indirectly related to surface-mining and reclamation. Although applied research will continue to dominate the research effort, basic research should receive greater emphasis.

The abuses of the past should serve as reminders of what may occur when existing knowledge about environmental protection and reclamation is ignored. These past practices are not representative of the mining and reclamation methods in use today. A discussion of present-day reclamation practices is as difficult as giving a resumé of agricultural technology. We can, however, review the basic concepts and procedures that apply to reclamation methods used in the United States. This information, reviewed in context with past practices and the current research emphasis, suggest the direction future reclamation practices may take. The disturbances resulting from surface-mining for coal may be considered an asset in future land-use planning. Land-management methods can and should be developed to fully utilize the productive capacity of the disturbed land.

PRE–MINING EVALUATION

Advanced planning of the mining operation was the predominant consideration in pre-mining evaluations of the past. Today there is a recognized interrelation between mining and reclamation. For example, many operators know that rock strata in the overburden above some coal seams are acidic and will restrict vegetation establishment and growth. The costs of a modified mining system that will bury this undesirable material are an integral part of the pre-mining plan. In the future, consideration will be given to plans that utilize both mining and reclamation practices to create areas for specific land-management objectives (table 1). These plans should maximize the potential productive capacity of surface-mining disturbance.

The quantity and quality of the coal reserve are the basis for judging the

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TABLE 1
Components of a coordinated mining and reclamation program.

I. PRE-MINING EVALUATION TO IDENTIFY LAND-USE OPTIONS
- Mining:
  - Quality of coal
  - Quantity of coal
  - Overburden characteristics
- Reclamation:
  - Overburden characteristics
  - Geographic location
  - Topographic features
  - Local land-use patterns
  - Legal limitations
  - Political factors
  - Social factors

II. POST-MINING EVALUATION TO SELECT THE MOST ATTRACTIVE LAND USE
- Chemical characteristics of the spoil
- Physical characteristics of the spoil
- Climatic variables
- Topographic variables
- Economic variables

III. REVEGETATION TREATMENTS TO ACHIEVE LAND-USE OBJECTIVE
- Site preparation
  - Amendments:
    - Fertilizers (nutrient supplements)
    - Neutralizing material (chemical and physical soil modifier)
    - Top soiling
  - Surface modification:
    - Seedbed preparation
    - Moisture retention
    - Modify surface temperatures
    - Reduce wind velocities
  - Species selection:
    - Compatability with spoil characteristics
    - Season of seeding
    - Species compatability
    - Climatic & topographic factors
    - Land-use objective
  - Seeding and planting systems:
    - Acreage to be treated
    - Physical characteristics of the spoil
    - Configuration of the surface

IV. MAINTENANCE SYSTEMS
- Vegetation characteristics
- Chemical and physical characteristics of the spoil
- Climatic variables
- Topographic variables
- Economic variables

economic benefits for initiating the mining operation. Overburden depth and the characteristics of the rock strata above the coal are major considerations in developing estimates of mining costs.

Recent studies indicate that the chemical and physical characteristics of the overburden rock strata may determine reclamation costs and the success of the revegetation treatments. The physical characteristics of the rock strata establish the rate of weathering, determine the erosion potential of the fresh and weathered surface material, and influence surface and subsurface moisture regimes. Chemical characteristics are influenced by the process and rate of weathering. The chemistry of the rock strata influences the concentrations of essential plant nutrients and toxic ion concentrations that affect plant establishment and the pollution hazard.

Overburden materials are a resource that we must learn to use. This concept will become more widely accepted when regional guidelines are developed to characterize physical and chemical characteristics of the rock strata above important coal seams (May and Berg, 1966; Berg and May, 1969; Grube *et al.*, 1973). Mining and reshaping systems can then be developed to systematically place overburden rock on the spoil pile so as to reduce pollution hazards and to create the most desirable medium for plant growth.

The chemical and physical characteristics of the overburden are important to land-use potential, but other factors need to be considered. These include geographical location, natural topographic features, local land-use patterns, and limitations imposed by law as well as by political, social, and economic factors. The plan must also include realistic funding for establishment and maintenance. A successful management plan should provide long-term economic and social benefits.

The decision to surface-mine coal at any location indicates that the operator believes the coal can be recovered profitably after considering the anticipated costs of mining, reshaping, and revegetation. The growing interest in, and the development of, surface-mining disturbances for specific uses suggests that the economic benefits from land-management options also should be considered in pre-mining evaluations.

POST-MINING EVALUATION

After mining and shaping have been completed, the site should be evaluated to assess the actual chemical and physical characteristics of the spoil surface. Specific treatment options can then be developed for vegetation and establishment. This evaluation will provide the information necessary for land-management decisions.

Mining and reshaping methods often determine the variance in the physical and chemical properties of the surface spoil. Today, mining and reshaping operations bury suspected toxic overburden and cover large rock fragments. Surface configuration must conform to state laws and permit the movement of equipment used in site preparation and revegetation treatments. The pre-mining plan should attempt to predict the physical and chemical characteristics of the spoil after these operations are completed. The post-mining evaluation documents the actual condition of the spoil surface so that an appropriate revegetation plan can be developed.

Interpretation of the post-mining evaluation relative to plant establishment requires knowledge of the interrelationship between plant growth and spoil characteristics. Spoil pH is an adequate indicator of soil quality for many land-management objectives. The pH of the spoil may not directly influence vegetation survival and growth, but it does determine the availability of nutrients and toxic ions for the plants. Selected field indicators are convenient and provide results adequate for most revegetation planning (Berg, 1969). Revegetation guides based on pH and texture have been developed for the acidic spoils of the eastern United States (Grandt and Long, 1958; Limstrom, 1960).

Similar guidelines may be developed for the alkaline spoils of the western United States. In the West, several soil characteristics, in addition to pH and texture, must be considered. Salt concentrations other than sodium may be high enough to affect plant survival and growth. Sodic or high sodium spoils may also occur. These, as well as other spoil characteristics, may be included in revegetation guides for western spoils.

Climatic, geographic, and topographic variables are important considerations in all coal regions. In the eastern United States, rainfall is generally adequate and well distributed throughout the year. Topographic variation may be important in the Appalachian coal field where elevations above 3,000 feet occur. The climate at higher elevations may influence species selection, because temperatures are generally cooler and the growing season shorter.

In the western United States, precipitation patterns and elevation differences are very important variables to consider in revegetation planning. Rainfall may total less than 10 inches per year and there is no consistent rain pattern during the growing season. Elevation differences and rainfall patterns determine the occurrence of native vegetation. These variables must be considered in revegetation planning.

Post-mining evaluation provides data

for developing specific revegetation options and for estimating the costs of achieving the intended land-use objective. Planned mining and reshaping should reduce the costs of revegetation, increase the chances for successful vegetation establishment, and provide more land-management options.

SITE PREPARATION

In many situations, site preparation is desirable before seeding and planting. This includes treatments that: benefit vegetation establishment and growth, satisfy laws and regulations relating to reclamation, and reduce environmental damage by controlling surface runoff and erosion.

Site-preparation treatments relating to revegetation may be classified under two general categories. Amendments applied to modify or supplement chemical or physical characteristics of the spoils and mechanical treatments used for seedbed preparation and to create configurations of spoil surface for microclimatic modification or moisture retention.

Most spoils are deficient in one or more essential plant nutrients. In some regions, this is considered a more serious problem than acidity (Plass and Vogel, 1973). It is widely accepted that nitrogen, if present, occurs at very low concentrations on fresh spoil. Evidence from spoils in the eastern and western United States indicates that spoils often are deficient in phosphorus. Potassium is usually adequate for vegetation establishment and to maintain a vegetative cover for site protection. Additions of potassium may be necessary on some sites to maintain acceptable yields of forage or row crops. There is little evidence of deficiencies for other macro- and micronutrients. More interest in these will develop as the intensity of management increases on spoils with a high productivity potential. On these sites, selected nutrient amendments may be justified to increase yields of pasture and forage and horticultural or agricultural crops.

Amendments to neutralize acidic conditions are commonly considered. The most frequently used material is agricultural limestone, but power-plant fly ash, bottom ash, and alkaline industrial slags may also be used (Plass and Capp, 1974). The materials used are limited to those that will not contaminate soil or water and rates of application depend on the desired change in pH, the neutralizing capacity of the material, and the chemical and physical properties of the spoil. Whenever possible, mechanical methods are used to incorporate the neutralizing material into the surface 6 to 8 inches of spoil. On extremely rocky spoils, where mechanical treatments are not possible, the neutralizing material may be carried into the soil by infiltrating waters and frost action.

Top-soiling is used when there is evidence to indicate that the surface of the spoil may be difficult to revegetate because of chemical or physical conditions. The treatment involves spreading a mixture of all natural soil horizons over the spoil surface. Seldom is it possible to segregate and use the most productive horizons of natural soils. This treatment was recommended in several Western States and can be used selectively on some eastern spoils.

Recommendations relating to application rates for top-soiling should be determined by the nature of the problem requiring modification. A thin application may be adequate to increase the percentage of soil-size particles in a coarse-textured spoil. Layers 12 inches or more in thickness may be required on areas having very low pH. The expense of the treatment requires careful consideration of alternative treatments. It may be more practical to place selected overburden rock on the surface during mining or reshaping than to relayer the soil.

Several research projects are investigating advantages and disadvantages of using various organic wastes on spoil areas. Of primary interest is the disposal of large quantities of a waste material. Investigations are often designed to investigate the advantages in using a particular material, or to identify the limitations imposed by the chemical, biological, or physical properties of the waste product. There is some evidence that many of the organic wastes produced by our society could be used to advantage on selected surface-mining disturbance. More research will be required before these wastes can be accepted for general use.

Many spoils develop a hard crust on the surface as they dry. This may influence germination and reduce the density of seeded vegetation. Mechanical scarification before seeding may be desirable. An alternative is to seed as soon as a slope is formed or when areas are freshly graded. Frost action may honeycomb the surface and create a desirable seedbed. Scarification after seeding is useful for covering large seed, but smaller seed may be buried to a depth that would interfere with seedling emergence.

In the western coal fields, the conservation of moisture and the trapping of all precipitation often aid in the establishment of vegetation (Sindelar *et al.*, 1973). Modification of the surface is accomplished with conventional as well as specialized equipment. Depressions or furrows are created to trap precipitation, modify surface temperatures, and reduce the wind velocity on the spoil surface. The use of artificial barriers such as snow-fencing may be used to increase the accumulation of snow (May and Lang, 1971). Orientation of these devices with regard to exposure to the sun and to the prevailing winds often determines their effectiveness.

SPECIES SELECTION

Selection of appropriate plant materials requires consideration of the chemical and physical characteristics of the spoil, the season of seeding, the compatability of all species established on a site, climatic and topographic factors, and the land-management objectives. In the midwestern and Appalachian coal regions, many species of grasses, leguminous forbs, trees, and shrubs are recommended for surface-mine revegetation. Guidelines indicating site limitations of many species are available in several publications.

Species evaluations in the western coal regions emphasized native plants. Evidence from range-reseeding projects and highway-revegetation programs indicated these will provide a more permanent cover once they become established. The seed for native species may be difficult to obtain, and establishment techniques may have to be developed.

The necessity to quickly establish a vegetative cover for reducing erosion may require seeding at any time during the growing season. Annual grasses are often used because they develop a fibrous root system and abundant foliage. Several warm-season species are being successfully seeded during late spring and summer. Cool-season grasses are used for late summer and fall seedings. Perennial grasses and leguminous forbs may be seeded with the annual cover crop or after the annuals mature.

If perennials are seeded with the annuals, failures may occur because the annuals compete aggressively for light, water, and nutrients. When annual crops are used, the revegetation plan should include provisions for retreatment to establish the perennial ground cover. In some situations, a small grain could be seeded with the intent of harvesting a crop. After harvest, a perennial forage crop may be seeded with little or no additional site preparation.

In the Appalachian and midwestern coal regions, perennial grasses and leguminous forbs, commonly used in agriculture for pasture and forage crops, are often included in the perennial seed mixtures. Native grasses are seldom used because they develop rather slowly and require two or three growing seasons to establish an effective erosion-control cover. Rainfall and topographic variability in the Western States require a more diverse group of plant species. Species recommended for range and forage crops can be used; but native grasses, forbs, and leguminous forbs are being considered. Experience in range-reseeding projects indicates that they may be more successful in areas having extremely harsh environments.

Woody plants are often recommended for permanent site protection, forest crops, and wildlife food or cover. Seedlings of native species are usually planted and direct seeding of pine species has been successful in the southern Appalachians. Black locust is seeded in the Appalachians and in the midwestern coal regions. Direct-seeding could be more widely used if reliable methods can be developed for seeding of desirable timber species or wildlife shrubs.

The arrangement and spacing of the woody plant seedlings are important considerations in planning for site protection and forest crops. Factors to consider are anticipated rate of growth, crown characteristics, and tolerance of competition. Species of trees or shrubs can be mixed to protect or to enhance the growth of species considered most desirable for the intended land-management objective. Species that are expected to grow rapidly may be used to provide protection from environmental extremes such as wind and temperature. There is also evidence that woody species capable of fixing atmospheric nitrogen may contribute to the increased growth of other species planted with them.

Species compatability is an important consideration in vegetation planning. The concept is recognized for agricultural crops, and species mixtures are recommended for most regions. The application of these principles and recommendations to surface-mining disturbance may require some modification. One of the most important requirements in surface-mine revegetation is to establish a cover crop as quickly as possible. This requirement often encourages the use of mixtures that ignore species compatability. The result may be that more frequent maintenance treatments are needed to retain acceptable density or yield.

Compatability between herbaceous ground covers and tree or shrub species is a recognized problem. State regulations relating to surface-mining usually require a grass and legume ground cover whether trees or shrubs are planted or not. Therefore, the influence of various herbaceous mixtures on tree growth is being studied There is evidence that some grasses and legumes are less competitive than others. When tree growth is important, mixtures of these species should be considered.

SEEDING AND PLANTING

Hand and mechanical methods are used to distribute grass or legume seed over areas disturbed by surface-mining. The size of the area to be treated, the stoniness of the spoil surface, and the configuration of the reshaped disturbance determines the method used for spreading seed. Conventional equipment used in agriculture may be adapted to areas that are gently rolling or nearly level. Cyclone spreaders mounted on motorized vehicles are adapted to most sites. Drills or seeders that place the seed in the ground are limited to sites relatively free of large rock fragments. Equipment specially designed for seeding rough, rocky surfaces is used to a limited extent.

Hydroseeders are used to seed steeply sloping land or to reach areas not accessible to other types of equipment. Slurries containing seed, fertilizer, and mulch may be applied in one operation. A reliable water supply near the area of application is a prerequisite for an efficient hydroseeding operation. A hose line controlled by a powdered reel is an auxiliary attachment that permits treatment of long slopes or remote areas.

Helicopters or fixed-wing aircraft may be used to seed large acreages. Seed size and wind conditions affect seed distribution patterns. This method is most efficient on large acreages, extremely rough terrain, or where ground conditions prevent treatment by equipment operating on the spoil surface.

Small tree and shrub seedlings can usually be planted by hand, using one of several planting tools. Specially designed mechanical tree planters may be used on selected areas relatively free of stones. Direct-seeding of trees and shrubs has had limited successs. Seed can be dispersed by hand, hydroseeder, helicopter, or fixed-wing aircraft.

Grasses can be established on selected sites by planting roots or stolons (sprigging). The relatively high cost of this method will limit its use to the better sites and to valuable forage species that are difficult to establish by other systems.

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