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Reclamation of Drastically Disturbed Lands

This book is a complete revision of the first edition with the same title. With a few exceptions, different authors than those of the first edition have written the chapters in this edition. These revisions follow significant changes in the coal mining reclamation requirements as a result of passage and implementation of the Surface Mining Control and Reclamation Act of 1977 (SMCRA, Public Law 95-87). Passage of this law essentially made many chapters of the first edition out of date by the time the book was published in 1978. The first edition (F.W. Schaller and P. Sutton, editors) was largely the result of proceedings from the Wooster, Ohio, symposium.

This edition is a cooperative effort of the American Society for Surface Mining and Reclamation (ASSMR) and the American Society of Agronomy as a part of mutual liaison activities between these two societies. Chapters and senior authors were suggested to the editorial committee by action of an ad hoc committee of ASSMR.

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14 Forest Land Reclamation

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I. INTRODUCTION

Forest land reclamation is the reclamation of land that was forested before mining for the purpose of restoring a productive forestry postmining land use. Ideally, it is a process of creating the best possible minesoil for trees and establishing a community of plant species that will develop, without further human intervention, into a healthy forest ecosystem. If it is the landowner's objective, the forest should be capable of timber production. In the event mined land was reclaimed as pasture or wildlife habitat with no subsequent management or maintenance, a native, productive forest should be capable of developing via natural forest succession in regions where forests are the climax vegetation.

Reclamation of disturbed land in today's regulatory environment is a complex process involving landowners, coal operators, and regulators (Zipper, 2000, see Chapter 7). These groups have different goals, and they may have different ideas about what constitutes desirable reclamation. Since coal operators often have no long-term commitment to the land, their goal is to mine, reclaim, and achieve bond release as cost-effectively as possible. After bond release, the landowner resumes responsibility for property taxes and future environmental liabilities. Consequently, it should be the goal of the landowner to have a post-mining land-use that generates income and enhances environmental stability. Regulators have responsibility for writing and enforcing regulations.

The Surface Mining Control and Reclamation Act (SMCRA) of 1977 has provisions such that biological factors are no longer the only important factors to consider regarding the establishment of trees. In a post-SMCRA mining business, tree establishment must be integrated with many other reclamation processes. Successful forest land reclamation requires that engineering, economic, and regulatory constraints be balanced with biological considerations to accomplish the objectives of all participants. This chapter is an attempt to review the multifaceted problems and procedures facing today's reclamationists interested in reclaiming forest land. The emphasis is on the eastern and midwestern regions of the USA since this is where most forest reclamation operations and research have occurred, and this is where climate and natural vegetation favor the reestablishment of commercially-productive forests. Most of the examples pertain to reclamation of land disturbed by coal mining, but the principles apply as well to land disturbed in other ways.

Since 1977, reclamation technology has been the domain of engineers and agronomists. Foresters usually became involved with mined land only after the area was already "reclaimed"; that is, after the mined area was returned to its approximate original contour, regraded, and revegetated with a herbaceous ground cover. This chapter was written with the philosophy that the entire reclamation process should be land-use specific, because reclamation that is good for grass is not necessarily good for trees (Ashby, 1982). When forestry is the postmining land use, the needs of trees must be considered throughout the entire reclamation process, and not as an afterthought. Surface mined forest land must be reclaimed in a fashion that allows trees not only to survive, but also to grow well and develop into a healthy, viable forest ecosystem.

II. HISTORICAL POST-SURFACE MINING CONTROL AND RECLAMATION ACT USE OF FORESTRY AS A POSTMINING LAND USE

The SMCRA specifies that lands "be restored in a timely manner to conditions that are capable of supporting the uses they were capable of supporting before any mining or higher or better uses" (Sect. 816.133). The regulations require that the premining land use be determined and used as the basis for reclamation, unless a higher or better use is selected by the miner based on "consultation with the landowner". In regard to criteria for approving an alternative land-use, the legislation stipulates that "the proposed uses must meet the following criteria: (1) there is a reasonable likelihood for the achievement of the use, (2) the use does not present any hazard to public health or safety, and (3) the use will not be impractical or unreasonable" (Sect. 816.133).

In the East and Midwest, where the pre-mining land use is often forest, conversion of forest land to grassland was common during the first 10 yr after passage of SMCRA (Davidson, 1984; Ashby, 1991; Burger & Torbert, 1990). By most regulatory interpretations, forest land is considered a lower-order land use compared to agriculture or developed land, and conversion of forest to hayland or pasture is legal. Theoretically, landowners could gain more utility from the land as a result of coal mining.

Although the intent of the law was to provide landowners more productive land, the widespread conversion of forest to grass that occurred in the early 1980s did not occur due to a real interest on the part of the landowner to use the land for agriculture. Although some grassland is used for pasture, most of it has never been grazed. Coal operators selected hayland/pasture as the postmining land-use because it was more convenient and less expensive than returning the land to forest. Hayland/pasture is efficiently established by sowing grass and legume seed with fertilizer and lime when needed. Forest land, on the other hand, involves the additional work, expense, and risk of tree planting. Tree planting is an extra step in the reclamation process that requires time and expense to plan and execute. If mined sites are not properly prepared for trees, the risk associated with tree planting is considerable. For these reasons, and an apparent apathy on the part of some landowners concerning future land-use, thousands of acres in the Appalachian and Midwestern coalfields were mined and converted to grassland, and ultimately abandoned to revert to early successional trees and shrubs.

During the mid-1980s, tree planting did increase in some states because coal operators had difficulty meeting success standards for hayland/pasture. Bond release for hayland/pasture requires that the reclaimed site produce as much forage as undisturbed soils used for pasture in the vicinity. In many cases, forage covers that were dense and lush during the first 2 yr after seeding declined in vigor by the end of the 5-yr bond period because the initial effects of lime and fertilizer diminished. In these cases, some coal operators decided it was more cost-effective to select forest land as the postmining land use. Today, the extent to which coal operators select hayland/pasture vs. forestry as a postmining land use seems to vary from state to state based on the ability of the minesoils to support forage species, the actual success standards that must be achieved, and the degree of stringency with which regulations are interpreted and enforced.

In the early 1990s, many landowners developed a keen interest in the potential for commercial forestry for their surface-mined properties. This was especially true in the southern and central Appalachians where much of the surface-mined land is owned by large corporations that are already managing their unmined property for timber production. In the past, these landowners were relatively unconcerned about the postmining land use selected for mined land. In the early post-SMCRA years, much of their land was reclaimed to hayland/pasture, or planted with non-commercial tree species such as black locust (Robinia pseudoacacia L.) or autumn olive (Elaeagnus umbellata Thunb.). After bond release, these landowners acquired responsibility for hundreds or thousands of acres of reclaimed land with little or no value. These landowners continue to pay taxes on this property and their legal departments are concerned about "environmental liability" for vegetation or slope failures that may occur in the future. Since most of this land is remote and has little or no present or future value, there is little opportunity to sell it. As these landowners deliberate their options for land management, they usually conclude that forestry is their only realistic postmining land-use opportunity. This decision is strengthened in some states such as West Virginia, where real estate taxes are lower on land managed for timber production. Consequently, more and more landowners are urging coal operators to reclaim the land to a forestry postmining land use. For these landowners, it is not sufficient merely to plant trees, but desirable tree species must be selected and they must grow well (Evans, 1980; Probert et al., 1992; Kyle, 1992).

III. FORESTRY LAND-USE OPTIONS

Many states allow several land-use options that involve tree planting. The exact definitions and success standards for each postmining land-use option vary from state to state, and often within a state, as regualtions are periodically rewritten or reinterpreted. Following are some general descriptions of land-use options that exist throughout the East and Midwest, listed in the order in which they provide genuine forestry land-use opportunities for the landowner.

A. Commercial or Managed Forest

Although seldom used, this land-use option provides the greatest opportunity for a productive forestry land use. This land use often requires 1000 stems ha^{-1} at bond release time, comprised of commercial tree species. Sometimes a lesser ground cover requirement exists to enhance the establishment of tree seedlings. Selection of this land use emphasizes the long-term intent of the landowner. Usually some evidence of a management plan from the landowner is required to assure the regulatory agency that the landowner is truly interested in pursuing a forest management option. Although seldom used, SMCRA allows the operator to acquire a variance, or experimental practice, to modify the original contour of land when managed for commercial purposes, including commercial forestry. This variance can be especially useful in mountaintop removal mining in the Appalachians. Some steep slope topography could be replaced with more level and gentle sloping land that would greatly reduce reclamation costs and result in more useful level land with deeper soils (Zipper et al., 1989).

B. Unmanaged Forest

Operators must establish 1000 to 1500 trees and shrubs per hectare across the entire area in conjunction with a ground cover (often 90% cover). A higher number of trees is sometimes required on slopes steeper than 20%. Generally, operators must establish at least four species of trees and some of the species must have commercial value. For example, in Virginia, operators are strongly persuaded to plant white pine *(Pima strobus* L.) as the commercial species. In the mid-1980s, unmanaged forest land became the most prevalent postmining land use in Virginia as operators switched from hayland/pasture. Between 1982 and 1992, 93% of mining permits issued in Virginia designated unmanaged forest as the postmining land use (Slack, 1992). Operators shifted to unmanaged forest land because they had difficulty growing enough grass to meet forage production standards for hayland/pasture. Ironically, they commonly had trouble establishing white pine for unmanaged forest land because there was too much competition from the grass. Hence, many operators shifted back to hayland/pasture.

C. Wildlife

Wildlife habitat has become a very popular land-use option in several eastern and midwestern states in recent years because it has less stringent requirements than unmanaged forest (Brenner, 2000, see Chapter 15 for more details associated with this land-use option). It often allows a sparser ground cover (70 vs. 90%), it may require fewer trees per hectare, or it may allow certain portions of the area to remain unplanted. Additionally, some states allow operators to establish trees and shrubs that have no commercial value. Operators often use this land-use option to plant species such as autumn olive, bicolor lespedeza (*Lespedeza bicolor* Turcz.), black locust, bristly locust (*Robinia fertilis* Ashe), black alder (*Alnus glutinosa* L. Gaertner) and other miscellaneous trees and shrubs. These species are relatively easy and inexpensive to establish on a broad range of minesoil conditions. These species can provide food and cover for many animal species, but they may provide no useful forest products for the landowner, and they may retard the natural invasion of more desirable native species.

D. Undeveloped Land

Ohio has a land-use option that allows operators to either plant seedlings or sow tree seed with the ground cover seed. The only requirement for this option is that a 70% ground cover be achieved and that healthy trees be planted or tree seed be sown. There is no requirement that seedlings actually survive or that the seed germinate and produce seedlings.

IV. SUCCESS STANDARDS FOR FOREST LAND

The SMCRA requires that crop productivity success standards be achieved before performance bonds can be fully refunded to the operator. For example, cropland used to grow corn (*Zea mays* L.) before mining must be restored as cropland, and the operator must demonstrate that the reclaimed cropland can produce as much corn as it did before mining. These success standards are important because they force the operator and regulators to manage reclamation processes to create a minesoil capable of supporting the postmining land use.

The success standards for forestry, however, are not based on productivity, "For areas to be developed for fish and wildlife habitat, recreation, shelter belts, or forest products, success of vegetation shall be determined on the basis of tree and shrub stocking and vegetative ground cover" (Sect. 816.116). Bond release is based on the number of surviving trees without regard to how well these trees are growing, or the likelihood that the established plant community will develop into a healthy, productive forest ecosystem. This is analogous to requiring only that a certain number of corn plants be established with no regard for whether or not the plants grow and produce corn. Some state regulations further stipulate that trees must be at least 30 cm tall and that at least 80% of the trees must have been alive for at least 2 yr. This height requirement is not really a measure of productivity, however, because many seedlings are already this height when they are planted.

Considering that timber production is a serious objective for some landowners, and considering SMCRA's requirement to return land to its original level of productivity, we believe that regulators should interpret regulations in a fashion that ensures the land can yield at least as much timber as it could before mining.

V. FOREST LAND PRODUCTIVITY

In forestry, site productivity (the quality of a minesoil for trees) is quantified by site index (SI). Site index is the height of dominant and codominant canopy trees at a selected age, for example, age 25 (Fig. 14-1). The average SI for white pine at age 25 on natural soils in the southern Appalachians is about 17 m (56 ft) (Doolittle, 1958). Some landowners believe their mined land could be reclaimed to SI 21 m (70 ft), but instead, their land is degraded by reclamation to a SI of about 14 m (45 ft) (Probert et al., 1992). Forest productivity is important to landowners because merchantable tree value increases exponentially with SI. Probert et al. (1992) estimated that the 30-yr value of white pine planted on a 3.5- by 3. 5-m spacing would be 10 to 15 times more valuable on a minesoil with SI 21 m (70 ft), than on a minesoil with SI 14 m (45 ft) (Fig. 14-1). Not only does the more productive site produce more timber, but the unit value of that timber also increases with SI. On SI 21-m (70-ft) land, trees are large enough after 30 yr to be sold as sawtimber, but on SI 14-m (45-ft) land, the trees can only be sold for pulpwood, mine props, or other low-value products (Table 14-1).

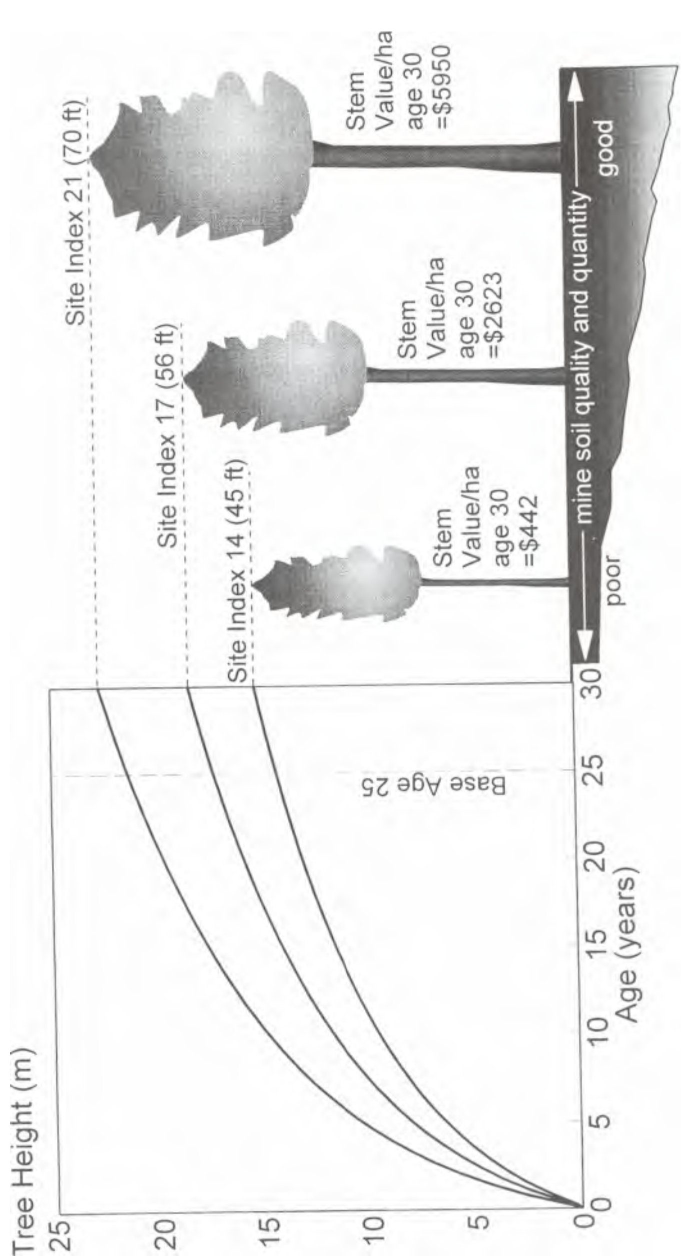
The lack of a productivity success standard for forest land is disturbing because there is a widespread perception among forest reclamation researchers that post-SMCRA reclamation is not creating sites as conducive for growing trees as occurred prior to SMCRA (Larson & Vimmerstedt, 1983; Davidson, 1984; Kolar, 1985; Burger & Torbert, 1990; Ashby, 1991; Plass & Powell, 1988). Good sites do occasionally occur, but more often by chance than by design. All of the above-mentioned authors provide overviews of problems created by SMCRA that either discourage tree planting or result in poor soil/site conditions for tree establishment and growth. Two universally cited problems are: (i) compaction from spoil grading, and (ii) competition from herbaceous vegetation.

Most authors acknowledge that today's forest land reclamation problems do not arise from SMCRA regulations per se, but instead from the manner in which some regulations are interpreted. Regulations are not often interpreted by state or U.S. Office of Surface Mining Reclamation and Enforcement (OSMRE) inspectors to require coal operators to create conditions conducive for tree growth. Instead of developing land-use-specific grading and revegetation guidelines, regulators generally expect operators to grade and revegetate the site using the same methods for forest land that would be required for hayland/pasture or wildlife habitat.

Within the regulatory boundaries provided by SMCRA, mechanisms need to be proposed by OSMRE that allow coal operators to cost-effectively reclaim the land and provide landowners with productive forest land. The development of such guidelines requires a good understanding of the minesoil factors influencing tree growth and the influence of reclamation factors on these minesoil properties.

VI. MINESOIL PROPERTIES AFFECTING FOREST PRODUCTIVITY

Surveys of some pre-SMCRA plantings have shown that productivity can be equal to, and sometimes better than. the productivity of premining soils. In



Tree Height (m)
25
20
15
10
5
0
0
5
10
15
20
25
30
Age (years)
Base Age 25
Site Index 21 (70 ft)
Site Index 17 (56 ft)
Site Index 14 (45 ft)
Stem Value/ha age 30 =$442
Stem Value/ha age 30 =$2623
Stem Value/ha age 30 =$5950
poor
mine soil quality and quantity
good

Table 14-1. Effect of minesoil site index (SI_{25}) on potential white pine harvest yield and value after 30 yr (from Probert et al., 1992).

Site index m (ft)	Harvest volume' MBF/ha^{-1}	Product	Harvest value ($\$/ha^{-1}$)
14 (45)	18	pulpwood	442
17 (56)	35	mixed	2623
21 (70)	79	sawtimber	5950

From Balmer and Williston (1983); MBF = thousand board feet (Int. 0.25-in. log rule).

eastern Kentucky, Wade et al. (1985) found that growth of several pine and hardwood species at age 17 rivaled the growth rates found on natural soils. In Illinois, Ashby et al. (1980) found white oak *(Quercus alba* L.) planted on a stony spoil bank with a SI (base age 50) of 28.6 m (94 ft), and yellow-poplar *(Liriodendron tulipifera* L.) on similar spoil with a SI (base age 50) of 29.6 m (97 ft). In Virginia, Torbert et al. (1988) found some stands of white pine on pre-SMCRA minesoils with a SI (base age 50) greater than 30 m (100 ft). A review of these studies show that all of these sites, all reclaimed prior to SMCRA, had at least four things in common: (i) the mine soils were deep, (ii) they were nontoxic, (iii) the mine soils were loose and porous (uncompacted); and (iv) there was an absence of dense herbaceous competition when trees were established.

In a comparison of mined and unmined soils in Indiana, Bussler et al. (1984) concluded that chemical properties of minesoils were generally equal to or better than those of adjacent unmined soils, but physical properties of minesoils were less conducive to tree growth. In particular, properties such as soil strength, aeration porosity, water holding capacity, and infiltration rates were poorer on minesoils as a result of compaction.

Minesoils in the Appalachian region are usually rocky, and may consist of more than 50% coarse fragments. Rocky soils, however, are not necessarily detrimental to forest productivity (Ashby et al., 1984). Rocky soils have a lower water holding capacity, but provided they are deep enough, the total amount of water is usually sufficient for trees (Sencindiver & Smith, 1978; Coile, 1953; Hanson & Blevins, 1979; Ammons, 1979). The effect of coarse fragments on water retention is most problematic in the short term because it can affect survival and growth of seedlings. Coarse fragments can reduce the adverse effects of compaction by providing voids between rocks that are not compressed. These spaces can help maintain infiltration and aeration, and they may hold water that can be used by roots. Some freshly exposed rock surfaces created by blasting release nutrients as they weather. It is common to find rocks in minesoils that are matted both between and within with roots from trees and other plants.

Depth to a restrictive layer is an especially important physical property controlling productivity of trees. In a study to evaluate the effect of various minesoil physical and chemical properties on 10-yr-old white pine growth at 36 pre-SMCRA sites in Virginia, the most important minesoil property was rooting depth

(Torbert et al., 1988). From regression analysis, a SI_{50} (site index, with the height of dominant trees at age 50) of 24 m (80 ft) for white pine was predicted for a depth of 72 cm. Several plots in the study that were more than I m deep had SI's greater than 30 m (100 ft).

In a more extensive study of white pine on post-SMCRA minesoils (Andrews et al., 1992), 78 sites across a three-state region were examined, and rooting depth was again found to be the most important minesoil factor affecting tree height. Growth was inversely correlated with slope steepness because the poorest growth occurred on level areas where compaction was most severe and soils were shallowest.

A. Minesoil Construction

In the process of returning mined land to its approximate original contour, coal operators may replace tens of meters of overburden material. One of the most important decisions affecting long-term productivity is the decision regarding spoil and topsoil placement at and just beneath the surface. This is the material that will serve as the rooting medium for the future. This spoil and recovered topsoil (if any) needs to be carefully selected and placed to avoid compaction.

According to SMCRA, coal operators are supposed to separately remove and store the topsoil and replace it over the regraded overburden. Furthermore, in the Midwest, operators may be required to separately recover and replace the B and C horizons in the case of prime farmlands (Dunker & Barnhisel, 2000, see Chapter 13). When topsoil is less than 15 cm thick, the operator can use all of the unconsolidated material below the topsoil (A, B, and C horizons), and treat it collectively as topsoil. In the Appalachians, where thin soils and steep slopes make recovery impractical, topsoil substitutes are commonly used. SMCRA allows operators to use selected overburden materials as a topsoil substitute if the operator can demonstrate "to the regulatory authority that the resulting soil medium is equal to, or more suitable for sustaining vegetation than the existing topsoil, and the resulting soil medium is the best available in the permit area to support revegetation" (Sect. 816.22). This regulation provides flexibility in its interpretation. The opportunity exists for regulators to decide whether overburden should be selected to support short-term revegetation species (grasses and legumes) or long-term revegetation species (trees).

B. Spoil Selection for Topsoil Substitutes

Coal seams throughout the USA are overlain by multiple strata of sedimentary sandstones, siltstones, shales, limestones, and miscellaneous other rocks. Methods to characterize these materials are given in Sobek et al. (2000, see Chapter 4). These overburden materials can differ greatly with respect to their physical and chemical properties, and their suitability as a growth medium for plants (Daniels & Amos, 1984). Several studies have been conducted to evaluate the influence of spoil type on tree growth. In a greenhouse study, Preve et al. (1984) found that a sandstone spoil was a better growth medium than a siltstone spoil for *Pinus* spp. seedlings established from seed. They reported that this particular sandstone spoil was better than the siltstone because it had better aeration, lower

Table 14-2. Comparison of tree production and forage production at age five as affected by topsoil substitute material (from Torbert et al., 1990a; and Roberts et al., 1988).

Rock mix treatment	Tree volume' (cm')	Forage production (mg ha-')
Sandstone (SS)	7269a"	3.9ab
2 SS/1 SiS	6936a	3.9ab
1 SS/I SiS	4972a	2.9b
1 SS/2 SiS	4259b	4.4a
Siltstone (SiS)	1783c	4.2a

'Volume index = $(\text{diameter})^2$ x height.

"Values within a column followed by different letters are significantly different at the 0.05 level of probability.

levels of soluble salts, and fewer coarse fragments. Schoenholtz et al. (1987) reported better pine seedling growth in a sandstone spoil partially because natural mycorrhizal infection of pine roots was greater in sandstone than in siltstone.

In a controlled rock-mix study, pitch (loblolly hybrid pine *(Pinus x rigitaeda)* grew better in a sandstone spoil than in a siltstone spoil (Torbert et al., 1990a). This rock-mix study was designed to evaluate the effects of these two spoil types and various blends of the two spoils. After 5 yr, trees in the pure sandstone plots averaged five times more stem volume than trees in the siltstone plots (Table 14-2). The sandstone spoil had a better pH for pine growth than the siltstone (pH 5.7 vs. 7.1). Siltstone had a higher coarse fragment content and lower amount of available water in the surface 20 cm. In a parallel experiment on the same rock-mix study, Roberts et al. (1988) found production of Kentucky-31 tall fescue (*Festuca arundinacea* Schreber) was greatest in the pure siltstone plots.

Results of the rock-mix study demonstrate that long-term forest productivity can be sacrificed if a topsoil substitute is selected for its ability to grow grass, a short-term objective. On reclaimed forest land, it is necessary to establish enough cover to reduce erosion, but given that trees will provide the long-term ground cover and erosion control, the topsoil substitute should be selected to favor trees.

The Midwest and southern Appalachian regions do not have the severe and widespread acid spoils that are common in the Appalachian region of Pennsylvania, Ohio, and northern West Virginia. In fact, tree establishment problems in the southern Appalachians are more likely to result from minespoil pH being too high as too low. In the southern Appalachians, much research was devoted to identifying spoil materials that are suitable for tree growth (Andrews et al., 1992; Torbert et al., 1988, 1990a, 1995; Schoenholtz & Burger, 1984). In this region, yellowish-brown-colored sandstone spoils derived from many different geologic formations have repeatedly been demonstrated to produce good growth of many tree species. These brown sandstone spoils that often exist immediately beneath the soil surface have a pH of approximately 5.0 to 5.5 and have low levels of soluble salts (<I dS m-'), which is typical of natural forest soils in the region. They fragment easily during the blasting process in mining and decompose rapidly after replacement at the surface. Within several years, many rock fragments crumble into a sandy soil.

Because this highly weathered overburden lies close to the surface before mining, it is relatively easy to separate from underlying strata and replace at the surface. A benefit to using this subsurface material is that it gets intimately mixed with the native topsoil. Even though the natural soil may be thin and infertile, it can improve the physical characteristics of the minesoil by increasing the overall fine-earth fraction and increasing the water-holding capacity. Furthermore, it contains a reservoir of seed and soil organisms that can give rise to many plant species that might otherwise remain absent (Davidson & Pollio, 1991; Wade, 1989). Also mixed with this blend of soil and rock are root stocks from hardwood species that often sprout and become established. Finally, because this spoil is suitable for trees, many tree species volunteer from windblown seed. It is common to see yellow-poplar, sourwood *(Oxydendrum arboreum* L. DC.), red maple *(Acer rubrum L.)*, birch *(Betula* spp.), sassafras *(Sassafras albidum* Nutt. Nees), pines, and other species become naturally established on brown, weathered, sandstone spoils.

Despite the obvious and demonstrated advantages in using the weathered sandstones as a topsoil substitute in the southern Appalachian region, operators commonly bury it in favor of using a near-neutral pH spoil predominantly derived from siltstone or shale. This occurs because operators' experiences have verified results of the above-mentioned rock-mix study. The higher-pH siltstones support better herbaceous vegetation. Brown, weathered sandstone often supports good grass growth for a year or two, but the initial effects of fertilizer diminish and ground covers are sparse by the 5th yr. The oxidized Fe that gives the brown sandstone its characteristic color causes a higher P-fixing capacity than that found in many siltstones. Because most trees are adapted to acidic soils and have a mycorrhizal association that enables them to extract P from iron phosphates, they grow better in the brown sandstone than grasses and legumes.

C. Compaction

Following a 30-yr assessment of tree plantings on graded and ungraded spoil in Ohio, Larson and Vimmerstedt (1983) concluded that spoil compaction was the most important SMCRA-related problem in need of solving for forest land reclamation. Compaction is caused during several steps of the reclamation process. It is most severe where rubber-tired scrapers and trucks are used, but compaction by bulldozers also can increase soil bulk density and strength to root-limiting levels (Holland & Phelps, 1986).

Compaction often arises during placement of the final lifts of topsoil or topsoil substitute, particularly on gentle slopes and level areas. On steep slopes, operators must compact the spoil as densely as possible as the slope is reconstructed in order to ensure slope stability. The surface meter of minesoil, however, can be looser, and in fact the surface of steep slopes is often fairly loose (Andrews et al., 1992). The compacting force from the tracked equipment working on the slope is not directly perpendicular to the surface of the slope and therefore is not as compressive as that of equipment working on level land.

On level areas, compaction can be severe. In the Midwest, where operators may be required to replace individual soil horizons, each horizon is separately trafficked by heavy equipment. Ashby (1991) argues that the practice of replacing individual soil horizons has no benefit for forestry, and unnecessarily increases the cost of reclamation and decreases soil productivity by destroying soil structure, increasing soil strength, and decreasing aeration porosity and water infiltration rate.

On level areas in the Appalachians, the final lift of overburden or topsoil substitute is frequently dumped by trucks and leveled with bulldozers. In the process, as trucks arrive at the area with more material to unload, they drive over the area that was just leveled and dump new material at the edge of the area. The material is then leveled by the bulldozer. Thus, dumping and grading occur simultaneously and the near-surface layers of minesoil become extremely compacted from the traffic.

After the landforming process is finished, a final grading pass may occur to smooth the surface and remove any protruding boulders, large roots, or any other debris that may be included in the spoil material. Finally, before the site is seeded, it is "walked in" or "tracked in", using a bulldozer to cover the entire surface with indentations from the bulldozer treads. This practice breaks the surface crust that may have developed between the time of grading and seeding, removes any rills or gullies that formed, and creates a uniform distribution of small microsites to capture grass seed and produce a uniform ground cover.

D. Minesoil Compaction Effects on Tree Growth

Early reports on the adverse effects of spoil grading on tree growth were presented by Limstrom (1952) and Chapman (1967). In Ohio, Larson and Vimmerstedt (1983) found that yellow-poplar height and diameter were 142 and 67% greater after 30 yr on ungraded vs. graded spoil banks. White pine height and diameter were 32 and 23% greater in the ungraded spoil.

In Illinois, Josiah and Philo (1985) contrasted the physical properties of unmined soil, ungraded spoil, and graded spoil. The bulk density of the ungraded spoil and unmined soil were both 1.3 mg m^{-3}, whereas the bulk density of the graded spoil was 1.8 mg m^{-3}. Four years after planting, black walnut *(Juglans nigra* L.) trees were 35% taller and stem diameter was 31% greater in the ungraded spoil compared to the graded spoil. Where graded spoil was loosened by ripping, height and diameter were increased 38 and 55%.

Torbert and Burger (1990b) compared the survival and growth of six commercially important tree species planted on two adjacent sites, each comprised of the same spoil material. One was operationally regraded and tracked in, and the other was left in a "rough graded" condition, without the final smoothing and tracking in (Fig. 14-2). After 2 yr, tree survival averaged 42% on the conventionally regraded site and 70% on the rough-graded site. For some species, average height growth was almost doubled by eliminating compacting processes.

In the above-mentioned study, researchers carefully handled and planted seedlings on the compacted and rough-graded minesoils. Operationally, tree planting suffers on compacted soils because it is difficult to properly plant

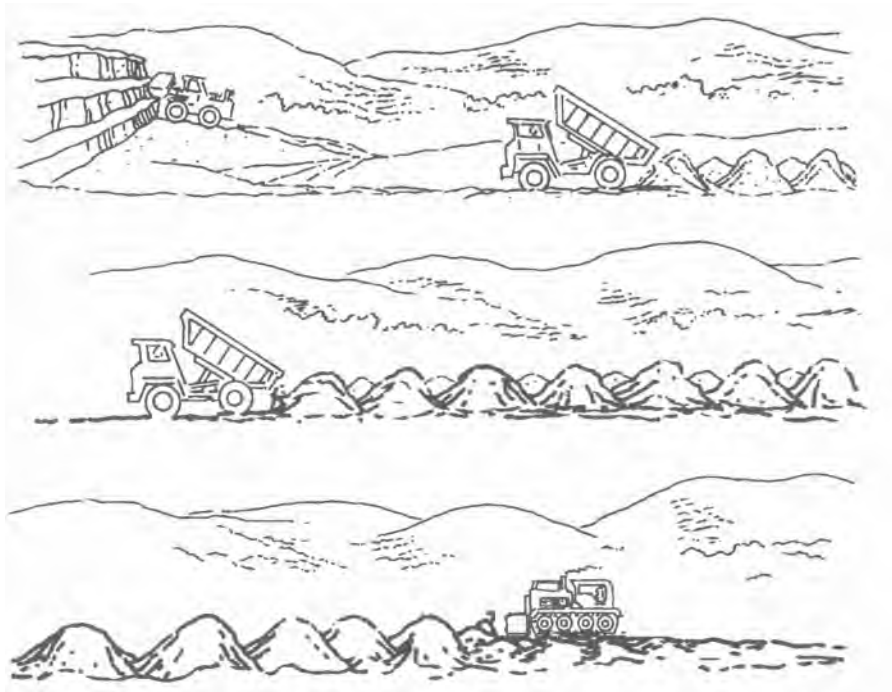


Fig. 14-2. A roughly-graded surface provides for good tree growth without increasing the risk of erosion. The final lift of soil on level areas should be lightly graded after all spoil has been placed on the surface.

trees in compacted soil. Hand-planting contractors, paid on a per-seedling basis, are less likely to make deep holes and to properly close the planting hole on compacted minesoil. Furthermore, recognizing their difficulty in opening deep holes, they will prune seedling roots to make a small root system that fits a shallow hole. The cumulative effects of root pruning and loose planting in a shallow hole lead to high mortality. Even if seedlings survive, growth will be limited by the high strength and limited water holding capacity of the compacted soil.

E. Preventing Compaction during Post-Surface Mining Control Reclamation Act Reclamation

1. Spoil Placement

Compaction that occurs during placement of the final lift of overburden can be avoided by doing the dumping and leveling in separate operations. On level areas, trucks delivering the final layer of overburden can place the spoil in tightly spaced piles across the whole area. After all the spoil is in place, a bulldozer (preferably a D-4 Caterpillar size) can knock the tops off the piles and gently level the area with one or two passes. The operator can create a looser, more productive soil and save a considerable amount of money by reducing the amount of bull-dozer work.

2. Surface Grading

After land shaping, any additional grading preceding seeding should be minimal. Since the initiation of SMCRA-based regulations, the result of reclamation throughout the USA has been the creation of a "golf course appearance" by making a smooth landscape quickly covered with lush grass. This reclamation scenario has become standard operating practice for most coal operators, and regulators have come to expect smoothly finished surfaces with dense vegetation. These practices may be desirable for creating a "hayland/pasture" land use, but they are counter-productive for reclaiming productive forests. For an agricultural land use, the land needs to be smooth enough to use farm equipment. Smooth land, however, is not necessarily desirable, and is not natural for many forest land areas. Forests in the Appalachians typically have rough surfaces strewn with rocks, depressions, and woody debris.

The SMCRA does not explicitly require the intensive degree of surface grading that has become so common. Section 816.102 pertains to general requirements for backfilling and grading, and states that "Disturbed areas shall be backfilled and graded to: (1) achieve the approximate original contour . . . , (2) eliminate all highwalls . . . , (3) achieve a postmining slope that does not exceed the angle of repose . . . , (4) minimize erosion . . . , and (5) support the approved postmining land use." The last requirement suggests that grading practices be land-use specific. When forestry is the postmining land use, level and gently sloping land (where erosion hazard is slight) should be less intensively graded. It should be acceptable to leave rocks and debris (logs, stumps, etc.) on the surface since they do not affect forestry land-use opportunities. It has been estimated that operators in the Appalachians could save about $500 ha' on surface grading costs by deliberately constructing minesoils conducive for tree growth (Torbert et al., 1994a).

3. Surface Grading Effects on Erosion

Roughly graded sites are less prone to erosion since the loose soil has a higher infiltration rate (Merz & Finn, 1951). In a discussion about mined land shaping and grading, Glover et al. (1978) listed five practices to reduce or detain surface runoff. First on the list was "roughening and loosening the soil" (followed by mulching and revegetation, topsoiling and use of soil amendments, reduction of slope length or gradient, and use of concave slopes). Minesoil that is left in a loose condition, either as a result of rough grading to avoid compaction, or by ripping to ameliorate compaction, has a greater infiltration rate that decreases overland flow and erosion. Furthermore, the lower strength of uncompacted soils is more conducive to root growth for trees and other plants, which ensures that better vegetative cover will result to further protect the soil.

Despite the common-sense knowledge that loose soils have a greater infiltration rate and less runoff than compacted soils, there is a common belief among some reclamation contractors and inspectors that intensive grading is necessary to reduce erosion. To dispel the belief that intensive grading is necessary to prevent erosion, a research/demonstration project was established in eastern Kentucky to evaluate the effect of surface roughness on ground cover establishment, erosion, and tree growth (Torbert & Burger, 1994b). A treatment that some might consider a worst-case scenario was compared with the standard grading operation used by this operator and a moderate grading treatment. Over a 3-yr period, deep ripping, directly up and down a steep (40%) slope, resulted in less erosion, better ground cover establishment, and better tree survival and growth than plots that were intensively graded in accordance with the operator's standard reclamation practices.

Other researchers have found ripping to be beneficial for improving tree rooting and growth, and have recommended ripping as a standard practice where trees are planted on minesoils (Josiah & Philo, 1985; Berry, 1985). Although ripping can ameliorate compacted soils, the wiser approach would be to avoid the compaction in the first place. Ripping is an expensive operation that could discourage operators from selecting forestry as a postmining land use.

VII. REVEGETATION

Revegetation of surface-mined forest land involves the establishment of an herbaceous ground cover and the planting of trees and/or shrubs. The successful establishment of vegetation is dependent on many factors, and there are many plant species available for reclamation. Vogel (1981) and Bennett et al. (1978) provide excellent overviews of the various herbaceous and woody species that are appropriate for reclamation with a description of the soil/site requirements and general recommendations for revegetation.

Next to compaction problems, the greatest hindrance to successful tree establishment is usually competition from herbaceous vegetation. SMCRA requires coal operators to revegetate disturbed areas "during the first normal period for favorable planting conditions after replacement of the plant growth medium" (Sect. 816.113). Specifically, operators must "establish a vegetative cover that is: (1) diverse, effective, and permanent; (2) comprised of species native to the area, or of introduced species where desirable and necessary to achieve the postmining land-use . . . , (3) at least equal in extent of cover to the natural vegetation of the area, and (4) capable of stabilizing the soil surface from erosion" (Sect. 816.111). Furthermore, "the reestablished plant species shall be compatible with the approved postmining land-use. . . ."

Historically, these regulations have been interpreted to encourage operators to strive for a quick and vigorous ground cover by sowing forage grass and legume species with fertilizer and lime when needed. Kentucky-31 tall fescue, red clover *(Trifolium pratense L.),* crownvetch *(Coronilla varia L.),* and yellow sweetclover *(Melilotus officinalis* Lam.) are commonly used. Again, this is a logical revegetation strategy for hayland/pasture, but not for forestland. These herbaceous species are not a natural component of forest ecosystems and they often interfere with tree establishment and native plant species (Wade & Thompson, 1990). It can easily be argued that their use contradicts the provisions of the above-cited regulation relative to native species and compatibility with approved land uses. Herbaceous ground covers can compete with trees for light, nutrients, and soil moisture, and some herbaceous species can directly antagonize some trees via alleopathy (Walter & Gilmore, 1976; Todhunter & Beineke, 1979). In some areas, the dense herbaceous vegetation provides cover for rodents that girdle seedlings and decimate a newly planted area. Furthermore, herbaceous covers attract deer that browse tree seedlings and destroy saplings by horn rub.

Application of herbicides around tree seedlings has been demonstrated to help tree establishment (Ashby, 1990; Davidson, 1984; Philo et al., 1983; Schoenholtz & Burger, 1984; Torbert et al., 1985), but this practice is expensive and not always very practical, especially on steep slopes. Others have experimented with partial seeding schemes that leave unsowed strips in which to plant trees (Vogel, 1980; Washburn et al., 1994). This technique works well on land sown by tractor and grain drill, but it is not relevant to rugged terrain revegetated by hydroseeding.

A. Tree-Compatible Ground Covers

The concept of a tree-compatible cover was discussed by Plass (1974), Larson and Schwarz (1980), and Vogel (1980, 1981). For the southern Appalachian region, specific seeding and fertilizer recommendations were developed for tree-compatible ground covers (Torbert et al., 1986a; Burger & Torbert, 1992). A tree-compatible ground cover is a vegetative cover designed to provide enough cover to stabilize the soil but not prevent the establishment of trees. Furthermore, a tree-compatible cover provides a beneficial role in the succession of plant species and development of an N cycle. A tree-compatible cover should include species with the following traits: (i) some rapid germinating species to provide initial erosion control; (ii) the species must be tolerant of minesoil conditions (moderately acid, low fertility) created for the purpose of achieving good tree growth; (iii) the cover should consist predominantly of grass and legumes that are short and not likely to severely overtop tree seedlings, and (iv) perennial legumes must be included to accumulate biologically fixed N for the development of an adequate N cycle capable of sustaining a healthy forest ecosystem.

The challenge to producing a successful tree-compatible ground cover is to produce enough cover in the 1st yr to stabilize the soil and satisfy regulatory requirements without excessively competing with tree seedlings. If this can be accomplished, the likelihood of survival for the planted trees is improved. Additionally, there is increased opportunity for native plants and trees to become established, either from windborne seed or from seed in the seed bank if natural soil was returned as part of the rooting medium. There is an abundance of plant species that will emerge from the native seed bank if they are not prevented from doing so by introduced reclamation species (Farmer et al., 1982; Davidson & Pollio, 1991). Wade and Thompson (1990) reported that a forest soil seed bank resulted in the establishment of 82 native or naturalized species, including seven tree species, with treatments that did not involve the establishment of a reclama-

Table 14-3. Species and fertilizer recommendations for a tree-compatible ground cover for minesoils in the Appalachians.

Species	Applicatio rate (kg ha-1)
Grasses	
Foxtail millet *(Setaria italica* L. P. Beauv.)	5
Redtop *(Agrostis gigantea* Roth)	2
Perennial ryegrass *(Lolium perenne* L.)	2
Orchardgrass *(Dactylis glomerata* L.)	5
Weeping lovegrass *(Eragrostis curvula* Schrader Nees)	2
Legumes	
Kobe lespedeza *(Lespedeza striata* var. Kobe)	5
Birdsfoot trefoil *(Lotus corniculatus* var. *corniculatus)*	5-10
Ladino clover *(Trifolium repens* L.)	3
Fertilizer	
N	50-75
P	100

tion herbaceous cover. In treatments where a reclamation cover was sown, only three native species survived from the seed bank after 2 yr.

Success has been achieved in the southern Appalachians by using the seed and added nutrients prescribed in Table 14-3. Foxtail millet *(Setaria italica* L. P. Beauv.) is an annual grass that germinates quickly to provide early soil protection. Foxtail millet is not a short species, but when sown at a low rate (5 kg ha-'), it does not produce a dense cover. However, it does produce enough leaf surface area to reduce the impact of raindrops. Foxtail millet should be sown in the spring when the danger of frost has passed. Since rye *(Secale cereale* L.) is more frost-hardy, it is an appropriate species for autumn seeding (30 kg ha-'). Perennial ryegrass and redtop are short grass species that will provide good cover in the 1st or 2nd yr. Because they are cool-season grasses, they are less competitive during the summer when trees are most susceptible to moisture stress. Kobe lespedeza is a short, annual legume that will provide some 1 st-yr cover, and it will re-establish itself by seeding if not displaced by more aggressive species.

On steep slopes, orchardgrass can be included to provide additional protection against erosion. Weeping lovegrass is a desirable grass species to include at very low rates (2 kg ha ') on harsh sites. Weeping lovegrass is tolerant of very acidic soil (Vogel, 1981) and germinates within a few days, thus providing an important erosion control component to steep, acidic sites where the erosion potential is high. It also was found to grow well on an alkaline (pH 7-8) dark-colored spoil on a slope with a southerly aspect during a very dry summer. Weeping lovegrass provided almost all of the 1st-yr ground cover in a study where virtually none of the other above-mentioned species survived the first summer (Torbert & Burger, 1994b). Kentucky-31 tall fescue is too competitive and should be avoided, although on steep slopes where erosion control is critical, it would be acceptable to use it at low rates (less than 10 kg ha-').

Perennial legumes are important components of the tree-compatible ground cover. Birdsfoot trefoil is a perennial legume that has performed extremely well on many Appalachian mined sites. Sericea lespedeza *(Lespedeza cuneata* Dum.-Cours. G. Don) should be avoided because it grows tall and presents a fire hazard during the fall and winter. A relatively recent variety of Sericea, Appalow,' tends to sprawl along the ground rather than grow upright; thus it is possible to achieve a dense cover that may be less than 30 cm tall. However, it is more competitive than birdsfoot trefoil and is not recommended.

As a group, the clovers are less suitable for tree-compatible ground covers. Most clover species require a pH and fertility levels that are higher than needed for trees, and many clover species such as red clover and yellow sweetclover are too aggressive during the 1st yr to be used with trees. An exception is ladino clover, which is tolerant of acidic soils and grows short enough to be used with trees. When used in combination with birdsfoot trefoil, ladino clover provides a good cover for the first 2 yr, and then gives way to birdsfoot trefoil, which forms a very dense cover by age five around the stand of established trees.

B. Fertilization Rates

For hayland/pasture, it is common to use N fertilizer rates of 100 to 200 kg N ha'. With tree-compatible covers only, 50 to 75 kg ha-' is recommended. A study that involved fertilizer rates of 0, 60, and 120 kg N ha-' with tree compatible species (birdsfoot trefoil and perennial ryegrass) indicated that the highest rate of N did not produce more measurable ground cover, but it did increase ground cover height and competitiveness and decreased tree survival (Torbert et al., 1986b). Fertilizer rates of 50 to 75 kg N ha' appear to be enough to provide the necessary nutrition to allow vegetation to get established, but do not provide enough N to cause the vegetation to become so vigorous that it overtops seedlings. Furthermore, many legumes will not fix atmospheric N if soil N levels are high enough to meet their needs. By using relatively low N fertilizer rates (by agronomic standards), grass will stay short, legumes will fix N, and trees will survive. With time, the N fixed by the legumes will accumulate in organic matter and ultimately benefit the trees, which will have their greatest nutrient demand when they are 10 to 20 yr old at the stage of crown closure (Jorgensen & Wells, 1987).

C. Creation of a Sustainable Nitrogen Cycle

A goal of forest land reclamation is to put in place a community of plant species that will develop into a healthy forest ecosystem without any further human intervention. To successfully establish a self-sustaining ecosystem on a soil derived primarily from raw blasted rock, it is necessary to establish a N cycle. Furthermore, provisions must be made such that the N supply will accumulate with time to supply the continuously increasing demand that trees will have as they approach crown closure.

Bradshaw et al. (1982) discussed issues related to the development of a N cycle on mined land. They believe a pool of at least 1000 kg N ha-' must be accumulated, after which N cycling via mineralization, plant uptake, and litterfall will support a self-sustaining ecosystem. They suggest that the N capital of the minesoil be supplied by replacing a sufficient quantity of topsoil, adding sewage sludge, or using legumes.

Based on a chronosequence study of 1- to 30-yr-old mined sites, Li and Daniels (1994) estimated a N accumulation rate of 24 kg N ha^{-1} yr^{-1} where sericea lespedeza was the primary legume responsible for N fixation. They commented that these N accumulation rates, mostly on pre-SMCRA sites, were low by comparison with today's practices that utilize more legumes that fix more N. Li (1990) reported that birdsfoot trefoil fixed N at a rate of 150 kg ha^{-1} yr^{-1} during the first 2 yr on a post-SMCRA reclaimed site. In a controlled lysimeter study with an unamended sandstone spoil and a ground cover similar to that listed in Table 14-3, Schoenholtz at al. (1992) found that 479 kg N ha^{-1} accumulated in the surface 10 cm during the first 2.5 yr of their study.

The use of an appropriate *Rhizobium* inoculum for the chosen legumes would be wise, since natural inoculation may otherwise be slow. Since P plays an important role on the N fixation process, P fertilization rates should be at least 100 kg P ha^{-1} for a long-term supply.

According to Bradshaw et al. (1982), the main period for N accumulation is the time when legumes dominate the vegetation. With trees, the herbaceous legumes will eventually be shaded and succumb to the overtopping trees. The period of N accumulation can be prolonged, however, by interplanting N-fixing trees and shrubs (Reinsvold & Pope, 1985).

D. Tree Species Selection

The long-term vegetation on reclaimed forest land consists of the trees that are planted, direct-seeded, or allowed to become established by natural processes. If the minesoil is properly constructed and the short-term herbaceous ground cover is not too competitive, trees should be easily established. Many species of trees and shrubs can be planted on mined land. Hart and Byrnes (1960), Limstrom (1960), Plass (1975), Bennett et al. (1978), Vogel (1981), and others have summarized site requirements for various reclamation species.

Desirable tree and shrub species can generally be divided into two categories: crop trees and N-fixing nurse trees or shrubs. Crop trees are long-lived species that offer value to landowners as potentially marketable timber. Suitable nurse trees serve to build the supply of soil N. Selected nurse trees are usually less expensive to plant and more likely to survive; thus, they are important in helping operators achieve the necessary number of stems required for bond release. Additionally, most nurse tree species are an excellent source of food and cover for many animals.

1. Crop Trees

The suitability of crop trees is region-specific. In Pennsylvania, where acidic spoils are common, only a few species of trees can be realistically planted with expectations of harvesting timber. These include red pine *(Pinus resinosa* Aiton), Japanese larch *(Larix leptolepis* Sieb. and Zucc.), northern red oak *(Quercus rubra L.),* and hybrid poplar *(Populus* spp.) (Davidson, 1984). In the Midwest, many mined sites are capable of growing bur oak *(Quercus macrocarpa*

Michaux), sycamore *(Platanus occidentalis L.),* green ash *(Fraxinus pennsylvanica* Marshall var. *pennsylvanica),* river birch *(Betula nigra L.),* bald cypress *(Taxodium distichum* L. Rich. var. *distichum),* sweetgum *(Liquidambar styraciflua L.),* black walnut, northern red oak, and pecan *(Carya illinoensis* Wagenh. K. Koch) if spoil compaction and herbaceous competition problems are overcome (Davidson, 1984). In the southern Appalachians, commonly planted crop trees include eastern white pine, loblolly pine *(Pinus taeda L.),* Virginia pine *(Pinus virginiana* Miller), yellow- poplar, northern red oak, white oak, and ash *(Fraxinus* spp.). Provided that a suitable minesoil is created to serve as the rooting medium, there is no reason to expect that any species native to the area would not grow well.

2. **Nurse Trees**

Nurse trees are often recommended for inclusion on mined land plantings because of their ability to enhance soil N levels. Historically, black locust has been one of the most commonly planted N-fixing species on mined land. Ashby et al. (1985) and Vogel (1981) cite many examples where black locust improved the growth of adjacent crop trees. It can be a nuisance species, however, if it is planted or seeded too densely. Its rapid growth can cause it to overtop and suppress trees (Davidson, 1984) and its thorny branches can damage terminal leaders of adjacent crop trees (Torbert et al., 1995).

European black alder, autumn olive, bicolor lespedeza, and bristly locust are other commonly used N-fixing trees or shrubs. Like black locust, black alder is easily established and grows rapidly. It seems to grow better than black locust on wet sites and extremely acidic soils (Vogel, 1981). Bristly locust is probably the most tolerant of acidic sites. Furthermore, it sprouts readily whenever its shallow root system is exposed by erosion, thus making it an excellent shrub to plant on acidic, erodible areas.

E. Tree Planting

Many attempts to establish trees have failed because of poor planting techniques or mishandling of seedlings before planting. Most coal operators rely on tree planting contractors for planting. Many contractors working on mined land have a poor understanding of the factors influencing tree survival and growth, and consequently they are unable to consistently achieve good survival. Poor seedling handling and planting techniques are especially likely to result in high mortality when trees are planted on compacted minesoil or in thick grass. Some of the more common tree planting problems encountered on minesoils are as follows.

1. Seedling Acquisition and Storage

Operators planting large quantities of seedlings should make arrangements with nurseries to be sure of an ample supply well in advance. It is not uncommon for coal operators or their tree-planting contractors to start looking for a supply of seedlings at the time trees should be planted, when suitable planting stock is no longer available. Good-quality planting stock is essential for good survival and early growth. Seedlings should be large enough to have a healthy root system, but not so large that it is not possible to properly plant the seedlings. Seedlings should be picked up from the nursery immediately before planting begins, and ideally the seedlings should be lifted from the nursery bed immediately before pickup. Seedlings must be stored in cool, moist, aerated conditions. If the operator or tree planter does not have cold storage facilities, only a few days' supply should be accepted from the nursery.

2. Seedling Preparation

There is a counterproductive tendency for tree planters to prune roots and shoots excessively. Pine seedlings should not be top-pruned at all, and hardwoods should not be pruned below the point of live buds. Roots should never be cut to less than 15 to 20 cm. During planting, roots must be protected from drying. Water-absorbing gels are often used as a root dip to prevent drying in the field before planting.

3. Planting

A responsible crew foreman should supervise the actual planting operation to make sure that trees are planted on a proper spacing, planted sufficiently deeply, and that planting holes are properly closed. Planting holes should be at least 15 to 20 cm deep, and the seedlings should have all of their roots in the hole. If hand-planted, planting holes should be made with "dibble bars", and tree planters should be discouraged from using "hoedads". Hoedads are commonly used for planting timber industry land on sandy soils in the southern USA where workers can plant thousands of trees per day. On rocky minesoils, however, hoedads have generally proven to be ineffective. Although conscientious planters can successfully plant trees with hoedads, it is probably safe to assume that most hoedad planters will make holes that are too shallow and poorly closed on hard or rocky soil.

4. Microsite Selection

On areas planted with a mixture of species, contractors often have each planter plant a different species. Thus, each row of trees consists of the same species, but adjoining rows are different species. Better seedling survival and growth, and a more natural-looking mixture of species, would result if contractors had each planter carry a variety of species, and each planter made an effort to put the right species on the right microsites. For example, if planters were carrying red oak with large roots, white pine, autumn olive, and black alder, they could plant an oak whenever an excellent planting hole in soft minesoil was encountered. White pine and black alder could be alternated on average spots, and autumn olive could be used on rocky and compacted spots. Additionally, site selection could be based on slope position, with green ash, for example, planted at the toes of slopes that are likely to be wetter, and white ash (*Fraxinus* americana L.) planted further up the slope on drier spots. Red oak and sugar maple (*Acer saccharum* Marshall) are better suited to northern aspects, whereas white oak and red maple are better for southern slopes. Very often planters can select microsites between patches of dense vegetation without significantly affecting the overall spacing of planted trees. Proper microsite selection requires a good understanding of minesoil properties affecting tree growth and some understanding of different species' site preferences. Admittedly, this may not be practical for many tree planting operations, but with proper supervision and training, substantial improvement in traditional practices should be possible.

5. Supervision

A lack of supervision of tree planting contractors is clearly an important reason for much of the tree mortality that has occurred on minesoils. Planting contractors paid on a per-seedling basis often lack the incentive to carefully plant each seedling or plant seedlings on a desired spacing. It is common to see seedlings planted on a very wide spacing on poor soils where it is difficult to make a good planting hole, and to see trees planted less than a meter apart on uncompacted minesoils where it is easy to plant. Proper spacing of tree seedlings is important. It also is not rare for unsupervised planters to put more than one seedling in a hole.

F. Use of Mycorrhizal Seedlings

Much has been written about the role of mycorrhizae and tree establishment on harsh sites (Marks & Kozlowski, 1973; Marx, 1980). In particular, *Pisolithus tinctorius* (Pt) has been important for establishing trees on acidic minesoils (Marx, 1975; Marx & Artman, 1979). Caldwell et al. (1992) reported successful establishment of Pt-inoculated red oak and Virginia pine on acidic abandoned mined lands, some with a pH less than 3.0. In other studies where minesoil pH was not as low, the benefits of Pt were less evident. In Virginia, Schoenholtz and Burger (1984) did not find an increase in survival or growth of three mycorrhizae-colonized pine species compared to non- colonized seedlings. In a following study, they determined that the presence of mycorrhizae did improve tree growth, but the occurrence of mycorrhizae on trees was unrelated to whether or not the seedlings were inoculated at time of planting (Schoenholtz et al., 1987). Natural infection occurred rapidly in the field, and often the Pt was displaced by indigenous fungi.

For moderately acidic soils, other species of mycorrhizal fungi may be useful for aiding tree establishment. Ford et al. (1985) experimented with four species of mycorrhizal fungi on a Piedmont clayey soil (Typic Kanhapludult, clayey, kaolonitic, thermic) with a pH of 4.5. Seedlings infected with *Scleroderma aurantium* had significantly larger shoots and roots than seedlings inoculated with other fungi, including Pt. For alkaline spoils, research is underway (Plant Health Care Systems, 1995, unpublished data) to develop an alkaline-tolerant strain of Pt that could be beneficial for tree establishment on alkaline spoils in the eastern and western USA.

G. Fertilization Tablets

Fertilization can improve the establishment of tree seedlings. Mays and Bengtson (1978) reported that in some cases broadcast application of fertilizers can improve tree growth on minesoils, but tree establishment can be hindered because broadcast fertilization excessively stimulates the growth of the surrounding herbaceous competition. The use of slow-release fertilizer tablets planted adjacent to the seedling has been suggested as a method for supplying nutrients to trees without stimulating the growth of surrounding vegetation. Fertilizer tablets have produced dramatic increases in early growth of Virginia pine and loblolly pine on minesoils (Schoenholtz & Burger, 1984), but they seem to have little or no effect on white pine (Funk & Krauss, 1965; Schoenholtz & Burger, 1984).

H. Direct Seeding Trees

Some research has been done with direct-seeded trees on both eastern and midwestern minesoils (Kolar et al., 1981). Most work, however, was conducted prior to the enactment of SMCRA, when reforestation problems from herbaceous competition were not as prevalent. The ease of establishment of black locust is well known, and on many sites seeding at rates of 3 to 5 kg ha' has resulted in dense stands of stagnated black locust. A study designed to evaluate the feasibility of direct-seeding black locust as a nurse tree, with white pine as a crop tree, on an uncompacted, steep, sandstone-derived minesoil, indicated that a seeding rate of 70 g ha' was sufficient to produce 250 to 500 locusts ha' (Torbert et al., 1995).

Loblolly pine is relatively easy to establish by direct seeding (Thor & Kring, 1964; Zarger et al., 1973; Plass, 1974), even in the presence of an herbaceous ground cover (Torbert et al., 1986b). White pine, however, appears to be more difficult to establish on minesoils by direct seeding (Davidson, 1980; Preve et al., 1984; Torbert et al., 1995). Even though some pines can be established by seeding, the risk of failure, the lack of control of spacing, and the cost of tree seed generally makes it impractical as a method for reliably establishing forests.

Direct seeding may be a cost-effective practical method for establishing heavy-seeded species such as black walnut and oak (Richards et al., 1982). Seedlings of these species are often relatively expensive. Tackett and Graves (1983) reported successful establishment and good growth of direct-seeded northern red oak, pin oak (*Quercus palustris* Muenchh.), and bur oak in Kentucky. They reported that the greatest obstacle affecting the successful establishment of trees by seed was herbaceous vegetation. They suggested the use of less competitive vegetation such as perennial ryegrass and birdsfoot trefoil. Success also depends on proper treatment of seed before sowing. Different species have different scarification and stratification requirements (USDA, 1974). For example, white oak needs to be planted promptly after seed collection in the fall, whereas red oak requires moist cold storage for several months prior to spring planting. Care also should be taken, to the extent possible, to minimize the potential for predation by rodents.

VIII. CONCLUSION

Many mined sites in the eastern and central USA were forested before mining and will ultimately end up as forest again. This will happen either as the result of carefully designed and executed reclamation, or by default through natural succession of abandoned hayland/pasture and wildlife habitat areas. There will be a big difference in forest productivity between the reclaimed forests that result by design rather than default, and this difference will have significant and meaningful implications for landowners and society. Healthy forests provide the landowner economic opportunities, and they provide society benefits from the many noncommodity amenities of healthy forests: slope stability, erosion control, watershed protection, Carbon capture, wildlife habitat, diversity, esthetics, etc.

Proper implementation of SMCRA requires consideration during reclamation of the postmining land use. Regulations are needed to provide flexibility to allow states to develop land-use-specific reclamation procedures. Accordingly, forest land should be reclaimed differently and it should be different from land reclaimed for hayland/pasture or cropland. Restoration of productive forest land requires the construction of a deep, noncompacted, nontoxic minesoil, and the use of a noncompetitive ground cover. This can be accomplished by: (i) selecting appropriate overburden materials for placement at the surface, (ii) preventing compaction on level and gently sloping surfaces, (iii) using a tree-compatible ground cover to enhance tree seedling survival and early growth, and (iv) using proper tree handling and planting techniques. In many parts of the USA, it is possible for operators to create minesoils for forests that are even more productive than some native soils. The opportunity exists to create a win-win-win situation where landowners acquire productive forest land, operators reduce their reclamation costs, and society benefits from healthy forest ecosystems.

IX. ACKNOWLEDGMENTS

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