RECLAMATION OF SURFACE-MINED FOREST LAND IN THE SOUTHERN APPALACHIANS

by

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(ABSTRACT)

Most of the surface-mined land in the southern Appalachian coal fields of Virginia, southern West Virginia, and eastern Kentucky is forested before mining. For a variety of reasons, most surface-mined land will ultimately return to forest, either by design or through natural succession. The usefulness of forests on reclaimed surface-mined land for providing timber management opportunities depends on whether or not the land is reclaimed in a manner which creates a productive forest soil. Surveys of tree plantings on land that was mined prior to enactment of the 1977 Surface Mining Control and Reclamation Act (SMCRA) have shown that trees will grow well where 1) minesoils are non-toxic, 2) minesoils are deep, loose, and uncompacted, and 3) tree seedling establishment is not hindered by competition from an herbaceous ground cover. Several experiments were conducted to develop practical recommendations for post-SMCRA reclamation of surface-mined forest land to create these desirable minesoil conditions. An experiment designed to evaluate the effect of two contrasting spoil types revealed that the type of overburden material used as a topsoil substitute can have long-term effects on tree growth. After five years, average tree volume in a sandstone spoil was five times greater than tree volume in a siltstone spoil. In the southern Appalachians, oxidized (brown) sandstone is a good overburden to use as a topsoil substitute for forest land reclamation. A second experiment was conducted to evaluate the effect of surface grading practices on erosion, herbaceous ground cover, and tree survival and growth. After five years, study results revealed that traditional grading practices caused excessive soil compaction that resulted in higher erosion and poorer tree growth than treatments that

left the soil in a loose condition. A third experiment was conducted to compare the effect of two herbaceous ground cover prescriptions (a tree-compatible ground cover versus the coal operator's standard revegetation mix) on the establishment of white pine (*Pinus strobus*) and black locust (*Robinia psuedoacacia*) by direct seeding versus hand planting seedlings. After five years, on a minesoil derived from brown sandstone and rough-graded to reduce compaction, the tree-compatible ground cover produced more cover than the traditional ground cover, and the site index of the reclaimed land was estimated to exceed 30 m (100 ft). Based on results of this long term research program, recommendations for establishing a productive forest, capable of providing timber within a 30 year rotation are: 1) select an oxidized (brown) sandstone spoil for placement at the surface, 2) roughly grade the final surface to avoid compaction, 3) establish a tree compatible ground cover to protect the soil without overtopping trees, and 4) select an appropriate mixture of tree species and carefully plant trees by selecting good micro-sites for each seedling.

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"Crafty men condemn studies, simple men admire them, and wise men use them" (Bacon 1625).

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INTRODUCTION

Appalachian resources

Timber and coal have been the economic mainstays of the southern Appalachian coal mining region for nearly 200 years. Timber was the early provider of jobs and economic development as vast resources of large hardwood sawtimber were harvested and cut into lumber or used for charcoal. In the early to mid 1900s, coal became king of the economy and there was an explosion of small coal mining communities in parts of the region that would otherwise have probably never developed. Today, coal mines are closing as the coal reserves are depleted. In the past 20 years as the real price of coal has declined and the need for labor has been reduced by automation, the coal industry is providing less support for the communities that once thrived.

Eventually, the timber industry may once again play a prominent role in the economy of the coal fields. Most of the region is destined to remain forested and much of it is owned by large corporations that have timber management programs. In fact many corporations are already managing their forest land, and as the demand for Appalachian hardwood timber continues to grow, increased forest management will occur and related forest products industries will grow. In the future, some of the Appalachian timber will come from trees grown on reclaimed surface mined land (Hopps 1994).

Forest-land reclamation

Forest-land reclamation is the reclamation of land that was forested before mining for the purpose of restoring land to a productive forestry post-mining land use. It is a process of creating the best possible minesoil for trees and establishing a community of plant species that will develop, without further manipulation by man, into a healthy forest ecosystem. If it is the landowner's objective, the forest can be used for timber production. Otherwise the forest follows natural succession and ultimately blends into the surrounding landscape such that eventually it will be difficult for most people to ever recognize the site was once surface mined.

Public Law 95-87, the Surface Mining Control and Reclamation Act (SMCRA), which was enacted in 1977, drastically altered surface coal mining and reclamation throughout the United States. SMCRA was primarily passed into law for the purpose of protecting people and the environment, but it also protects the utility of the land for future use. Under SMCRA, coal mining companies in the United States must reclaim mined land in a fashion that renders the land at least as productive after mining as it was before mining. Before mining, the coal operator and the landowner (which are often two separate entities) must agree on a post-mining land use, and the coal operator must reclaim the land in a manner to support this designated land use. A performance bond posted by the coal operator cannot be fully returned for at least five years, and only after reclamation is judged to have satisfactorily achieved certain standards of success that are specifically defined by state regulations for each land-use option.

Reclamation in today's regulatory environment is a complex process involving landowners, coal operators, and regulators. 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. State and Federal regulators have responsibility for enforcing regulations.

The realities of modern day reclamation are 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 all participant's objectives.

It is important to note the distinction between "*reclamation of forest land*" and "*reforestation of reclaimed land*". The latter has been the traditional approach in the coal mining industry. Historically, reclamation technology has been the domain of engineers and agronomists, and reclamation was conducted without much thinking about how reclamation would affect forest productivity. Foresters got 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 an herbaceous ground cover.

Research conducted for this dissertation was conducted with the belief that the entire reclamation process should be land-use specific, because as pronounced by Ashby (1982), what's good for corn is not necessarily good for trees. When forestry is the post-mining 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 to not only survive, but also to grow well and develop into a healthy, viable forest ecosystem.

Historical post-SMCRA use of forestry as a post-mining land use

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*" (Section 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 based on "*consultation with the landowner*". In regard to criteria for approving an alternative land use, the regulations stipulate 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*" (Section 816.133).

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

Although the intent of the law is to provide landowners more productive land, the widespread conversion of forest to grass that occurred in the early 1980s was not often a result of 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 and was never intended to be grazed. Coal operators selected hayland/pasture as the post-mining land use because it was more convenient and less expensive than returning the land to forest. Hayland/pasture could be efficiently established by sowing grass and legume seed with fertilizer and possibly lime. 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. The risk associated with tree planting is considerable because seedling mortality is common and often requires continued expenses for replanting and delayed bond release. For these reasons, and an apparent apathy on the part of landowners concerning future land use, thousands of acres were mined and converted to grassland, and ultimately abandoned to revert to trees and shrubs via natural succession.

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 demonstration that the reclaimed site can 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 few years, declined in vigor by the end of the 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 post-mining land use. Today, the extent to which coal operators select hayland/pasture versus forestry as a post-mining land use seems to vary from state to state based on 1) the ability of the minesoils to support forage species, 2) the actual success standards that must be achieved, and 3) the degree of stringency with which regulations concerning post-mining productivity standards are interpreted and enforced.

In the early 1990s, many landowners developed a keen interest in the forestry land-use opportunities of their surface-mined properties. This is especially true in the southern Appalachians where much of the surface-mined land is owned by large corporations, which are already managing their unmined property for timber production. In the past, these landowners were relatively unconcerned about the post-mining land use selected for mined land. In the early post-SMCRA years, much of their land which was reclaimed to hayland/pasture, or planted with non-commercial tree species such as black locust (*Robinia psuedoacacia*) or autumn olive (*Elaeagnus umbellata*). After bond release, these landowners acquired responsibility for hundreds or thousands of acres of reclaimed land with little or no practical value for any land use. These landowners continue to pay taxes for this property and some of 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 remotely located and cannot be used for any other purpose, landowners do not even have a realistic opportunity to sell much of it. As these landowners deliberate their options for land management, they conclude that forestry is their only realistic post-mining land-use opportunity. This decision is strengthened in some states such as West Virginia, where real estate taxes are lower on forest land that is actively managed for timber production. Consequently, more and more landowners are urging coal operators to reclaim their land to a forestry post-mining land use. For these landowners, it is not sufficient to merely plant trees, but desirable tree species must be selected and they must grow well (Evans, 1980; Probert et al. 1992, Kyle 1992).

Forestry land-use options

Many states allow several land-use options that involve tree planting. The exact definitions and success standards for each post-mining land-use option vary from state to state, and often, within a state, as laws 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 by which they provide genuine forestry land-use opportunities for the landowner.

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}, comprised of commercial tree species. Sometimes a lesser ground cover requirement exists to ease 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 land option. Although seldom used, SMCRA allows the operator to acquire a variance on returning land to it's approximate original contour for land 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).

Unmanaged forest. Operators must establish 1000-1500 trees and shrubs ha^{-1} 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. In Virginia, for example, operators are strongly persuaded to plant white pine (*Pinus strobus*). In the mid 1980s, unmanaged forest land became the most prevalent post-mining land use in Virginia as operators switched from hayland/pasture. Between 1982 and 1992, 93% of mining permits issued in Virginia selected unmanaged forest as the post-mining 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 again shifted post-mining land-use designations, to wildlife habitat.

Wildlife. This has become a very popular land-use option is several eastern states in recent years because it has less stringent requirements than unmanaged forest. It often allows a sparser ground cover (70% versus 90%), and it may require fewer trees per ha 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*), black locust, bristly locust (*Robinia fertilis*), black alder (*Alnus glutinosa*) 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 also provide food and cover for many animal species, but they provide no useful forest management opportunities to the landowner, and they may retard the natural invasion of more desirable species.

Success standards for forest land

SMCRA requires that success standards be achieved before performance bonds can be fully refunded to the operator. SMCRA contains some minimum requirements for success standards, and individual states can adopt more stringent standards. Many states have adopted the language of SMCRA almost verbatim into state regulations. As already mentioned, the success standards for hayland/pasture are quite specific: "*For areas developed for use as grazing land or pasture land, the ground cover and production of living plants on the revegetated area shall be at least equal to that of a reference area or such other standards approved by the regulatory authority*" (Section 816.116). Operators must demonstrate the site can produce a defined quantity of forage or support a defined quantity of livestock. Similarly, cropland that was used to grow a crop (ie.

corn) before mining must be restored as cropland, and the operator must demonstrate that the reclaimed crop land can produce as much corn as it did before mining. These success standards are useful because they force the operator and regulators to manage reclamation processes to create a minesoil capable of supporting the post-mining 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*" (Section 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 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 0.3 m (1 ft) tall and that at least 80% of the trees must have been alive for at least two years. This height requirement is not really a measure of productivity, however, because many seedlings are already this height when they are planted.

Forest-land productivity

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, regulators should interpret regulations in a fashion that ensures the land can yield at least as much timber as the land could before mining.

In forestry, site productivity is quantified by site index (SI). Site index is the height of dominant and codominant trees at age 50. The average SI for white pine on natural soils in the southern Appalachians is about 24 m (80 ft) (Doolittle, 1958). Some landowners believe their mined land could be reclaimed to a SI 30 m (100 ft), but instead their land is being degraded by reclamation to a SI of about 20 m (65 ft) (Probert et al. 1992). Forest productivity is important to landowners because merchantable tree volume increases exponentially with SI. Probert et al. (1992) estimated that the 30-year value of white pine planted on a 3.5 m x 3. 5 m spacing would be nine times more valuable on a minesoil with SI 30 m (100 ft) than SI 20 m (65 ft). Not only does the more productive site produce more timber, but the unit value of that timber also increases with SI. On SI 30 m (100 ft) land, trees are large enough after 30 years to be sold as sawtimber, but on SI 20 m (65 ft) land the trees can only be sold for pulpwood, mine-props, or other low-value products (Table 1).

The lack of a meaningful 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 (Larsen and Vimmerstedt 1983, Davidson 1984, Kolar 1985, Burger and Torbert 1990, Ashby 1991, Plass and Powell 1988). Good sites do occasionally result, but more often by chance than design.

Minesoil properties that influence tree growth

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 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 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). Stony soils have a lower water holding capacity, but provided soils are deep enough, the total amount of water may be sufficient for trees (Sencindiver and Smith 1978). 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 aren't compressed. These spaces can help maintain infiltration and aeration, and they may hold water which can be used by plants. Some freshly exposed rock surfaces created by blasting release nutrients as they weather. It is common to find rocks in minesoils that are matted 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 designed to evaluate the effect of various minesoil physical and chemical properties on 10-year-old white pine growth at 36 pre-SMCRA sites in Virginia, the most important minesoil property measured was rooting depth (Tuladhar 1986). From regression analysis, a SI 24 m (80 ft) for white pine was predicted from a depth of 72 cm. Several plots in the study that were more than 1 m deep had site indices greater than 30 m (100 ft).

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

Surveys of some pre-SMCRA plantings have shown that productivity can be equal to, and sometimes better than, the productivity of pre-mining soils. In Eastern Kentucky, Wade at 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*) planted on a stony spoil bank had a site index of 29 m (94 ft), and yellow-poplar (*Liriodendron tulipifera*) on similar spoil had a site index of 30 m (97 ft). In Virginia, Torbert et al. (1988) found some stands of white pine on pre-SMCRA minesoils with a site index greater than 30 m (100 ft). A review of these studies shows that all of these sites, which were reclaimed prior to SMCRA, had at least three things in common: 1) they were non-toxic; 2) they were deep and uncompacted, and 3) there was an absence of herbaceous competition when trees were established.

Creating productive minesoils under post-SMCRA regulation

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 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. Within the regulatory boundaries provided by SMCRA, mechanisms need to be proposed that allow coal operators to cost-effectively reclaim the land and provide landowners with productive forest land.

OBJECTIVE

This dissertation reports results of several experiments conducted as part of a long-term research and extension program conducted with support from the Powell River Project, Pocahontas Land Corp., and Martiki Coal Corp. The overall goal of this forestry research was to develop practical guidelines for surface-mined forest land that comply with SMCRA regulations and provide meaningful benefits to the coal operator and landowner.

The following chapters contain literature reviews and results of original field research pertaining to important steps in the forest reclamation process:

1) Minesoil construction: Influence of overburden rock type on tree growth. This chapter contains an overview of soil/site studies conducted on minesoils and summaries of important minesoil properties influencing tree growth. The focus of this chapter is a rock mix experiment that was conducted (Torbert et al. 1990).

2) Minesoil construction: Influence of grading intensity on herbaceous ground cover, erosion, and tree establishment. This chapter contains the results of an experiment on the causes and effects of minesoil compaction. The experiment was conducted in Kentucky to evaluate the effect of grading treatments on erosion, ground cover, and tree establishment (Torbert and Burger 1994).

3) Revegetation: Tree-compatible ground covers and tree establishment. This chapter is devoted to issues related to establishment of short-term vegetation (herbaceous ground cover) and long-term vegetation (trees and shrubs). It is based on research dealing with tree-compatible ground covers, tree species selection, and reclamation techniques to improve tree establishment. The experiment was established in West Virginia on a site where minesoil conditions were known to be optimum for white

pine growth. The primary purpose was to determine the productive potential of white pine on properly reclaimed minesoils, and to evaluate several establishment techniques for white pine and black locust (Torbert et al. 1995).

4) Tree planting guidelines for Appalachian minesoils. Practical application of results of the above-mentioned experiments are combined with recommendations for tree planting surface-mined land.

Each of the three above-mentioned experiments are reported with fifth year results. Fifth year results are especially meaningful in reclamation research because of the implications they present with respect to bond release decisions. Any treatment determined to be conducive to forest productivity must be compatible with the goals and objectives of the coal operator and regulators. No reclamation practice can be considered feasible if it does not produce fifth year results that are in compliance with SMCRA regulations and achieve the success standards for bond release.

The above-mentioned studies are located within a three state region, with one study in each state. This was deliberately done to validate the region-wide applicability of this research to the southern Appalachian coal mining region of Virginia, southern West Virginia, and eastern Kentucky.

MINESOIL CONSTRUCTION: INFLUENCE OF OVERBURDEN ROCK TYPE ON TREE GROWTH

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 placement at the surface. This is the material that will serve as the rooting medium for the indefinite future. This spoil needs to be carefully selected and then 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. In the midwest, operators may be required to also separately recover and replace the B and C horizons. 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*" (Section 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).

Coal seams throughout the U.S. are overlain by multiple strata of sedimentary sandstones, siltstones, shales, and miscellaneous other rocks. These overburden materials can differ greatly with respect to their physical and chemical properties, and their suitability as a growth medium for plants (Daniels and Amos, 1984). Several studies evaluated 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 levels of soluble salts, and fewer coarse fragments. Schoenholtz and Burger (1984) reported better pine seedling growth on a minesoil primarily derived from sandstone than a soil primarily derived from siltstone. Natural mycorrhizae infection of pine roots was greater in the sandstone versus siltstone spoil (Schoenholtz et al. 1987).

Objectives

The purpose of this study was to evaluate the influence of two dissimilar overburden materials on tree survival and growth. Specifically, the objective of this experiment was to evaluate the difference in fifth year survival and growth of pitch x loblolly hybrid pine (*Pinus x rigitaeda*) as affected by a sandstone spoil versus a siltstone spoil and controlled ratios (1:1, 1:2, and 2:1) of these two spoils.

Methods

The study plots were constructed during the winter of 1982 on a previously mined flat bench in Wise Co. Virginia. The study consisted on four replications of five overburden mixes: pure sandstone (SS), pure siltstone (SiS), a 1:1 ratio of SS:SiS, a 1:2 ratio of SS:SiS, and a 2:1 ratio of SS:SiS. Treatments were arranged in a randomized complete block design. The overburden was obtained from an adjacent mining operation involving the Taggart and Taggart Marker coal seams of the Marcum Hollow member of the Upper Wise Formation. The spoils were blended to create the appropriate treatment mixture and placed in the center of 3.05 x 6.1 m plots. After all spoil mixtures were in place, each pile was graded flat with a small (D-4 Caterpillar) bulldozer, taking care to minimize compaction. When grading was finished, the area was flat and the loose spoil was 1.25 m deep to the underlying compacted bench.

The entire study area was fertilized with 168 kg/ha N, 147 kg/ha P, and 137 kg/ha K, as NH_4NO_3, $(NH_4)_2HPO_4$, and KCl. During May 1982, all plots were mulched with straw (2700 kg/ha) and hydroseeded with a slurry containing Kentucky-31 tall fescue (*Festuca arundinacea* Schreb.; 80 kg/ha) and wood fiber mulch (840 kg/ha). Half of each plot was used for a parallel study evaluating the effects of spoil type on tall fescue yields and nutrition (Daniels and Amos 1984; Roberts et al. 1988).

In April 1983, the portion of each plot used for this study was broadcast sprayed with glyphosate to kill the herbaceous vegetation, and 12 containerized pitch x loblolly hybrid pine seedlings were planted on a .75 m x .75 m spacing. Tree seed for these seedlings was collected from a 15-year-old pitch x loblolly pine seed orchard at Virginia Tech's Reynolds Homestead Agricultural Research Center on the Virginia Piedmont. Pine seedlings were grown in a greenhouse from this seed in Spencer-Lamaire root trainers (Hillson model 150 cc/cavity) for 16 wk prior to planting. Seedlings were planted with a 21 g slow-release fertilizer pellet (20-10-15).

After the third growing season, foliage was collected from fully-elongated current years foliage from the top third of each tree and a composite soil sample was collected from each plot. Soil samples were taken by collecting all soil within two randomly located 30 cm x 30 cm areas to a depth of 20 cm in each plot. Tree height and basal diameter were measured after the second, third, fourth, and fifth growing season.

Soil samples were sieved to separate coarse fragments from the fine-earth fraction (<2mm). Coarse fragment content was determined by weight. Of the fine-earth fraction, percent sand was determined as the oven-dry weight of particles trapped by a no. 270 sieve, percent clay was determined from 2-hr hydrometer readings, and percent silt was calculated by difference. Moisture retention of the fine-earth fraction was determined at field capacity (33 kPa) and permanent wilting point (1500 kPa) during the second growing season (1994), and moisture retention was reported as water available between 33 and 1500 kPa on a whole-soil basis by Roberts et al. (1988). Soil pH was determined in a 1:1 soil/water mixture with a glass electrode, and soluble salts were determined by measuring the electrical conductivity of a 1:5 soil/water extract. Exchangeable phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) were extracted with

1 *M* NH_4OAc and determined by colorometric spectrophotometry (P), atomic absorption spectrophotometry (Ca and Mg), and flame emission (K).

Needle tissue was dried to a constant weight at 65 C and ground in a Wiley mill to pass a 1-mm screen. Foliar nitrogen (N) was determined colorimetrically after Kjeldahl digestion. To determine foliar P, K, Ca, Mg, iron (Fe), zinc (Zn), manganese (Mn), and sodium (Na) concentrations, samples were dry ashed at 450 C, extracted with 6 *M* HCl, and analyzed with an inductively coupled emission spectrophotometer.

Results and Discussion

Survival of pines averaged 91% and was not significantly affected by rock type (Table 2). Individual tree volume, however, was significantly correlated (r= .82) with the proportion of sandstone in the rock mixture and tree volume. Trees in pure sandstone plots had the highest average height and diameter; 1.91 m and 4.6 cm, respectively. Height and diameter in the siltstone averaged 1.12 m and 2.5 cm, respectively. The average tree volume in sandstone plots was almost five times greater than siltstone plots (1858 cm^3 versus 382 cm^3).

Caution must be exercised using data from this experiment to explain the effect of rock mix on tree growth, because virtually any physical or chemical property that differs between the sandstone and siltstone (Tables 3, 4) will accordingly be correlated with tree growth. Multiple regression cannot be used because none of the soil properties are independent of each other. Nonetheless there is some value in looking at the differences between these two spoil types and conjecturing about probable cause and effect relationships.

The physical property that varied the most between these two spoil types was coarse fragment content (Table 3). The siltstone had a higher coarse fragment content than the sandstone (74% versus 52%). The textural classification for the fine-earth sized fraction (<2mm) was *extremely gravelly sandy loam*, for both spoil types, even though the sandstone had a higher percentage of sand (74% versus 57%) and less silt (15%

versus 29%) than the siltstone. Primarily because of the difference in coarse fragment content, the whole-soil water holding capacity of the sandstone plots was almost twice as high as the siltstone plots (43 g kg^{-1} versus 24 g kg^{-1}). This difference in available water would be most important in the first few years after planting seedlings. As trees grow older, stoniness is not necessarily detrimental to forest productivity provided the soil is deep and uncompacted (Ashby et al. 1994), which was the case for this study area. Since seedling survival was not correlated with rock mix, it doesn't appear that water availability was a strong factor affecting tree growth.

An important chemical property that differed between these two spoil types was pH (Table 4). The sandstone had a lower pH than the siltstone (pH 5.7 versus 7.1). Tree volume was more strongly (negatively) correlated (r = -.93) with minesoil pH than any other physical or chemical property. Most natural forest soils have a pH between 4.5 and 5.5, thus these levels are higher than normal and the siltstone pH appears to be critically high. The siltstone pH may be acceptable for some hardwood species, but not for loblolly pine (*Pinus taeda*) or pitch pine (*Pinus rigida*). Compared with agronomic crops, and hardwoods, conifers are better adapted and more productive on acidic soils. Part of this adaptation has to do with their symbiotic association with mycorrhizal fungi, that play an important role in the rhizosphere of conifers (Marks and Kozlowski 1973). Most ectomycorrhizae associated with pines do not thrive when soil pH exceeds 6.5 (Theodorow and Bowen 1969). Schoenholtz et al. (1987) found better mycorrhizal inoculation for three pine species growing on a spoil pH 5.4 to be better than a predominantly siltstone spoil with a pH of 6.1.

The sandstone spoil had a lower level of soluble salts, and lower levels of exchangeable K, Ca, and Mg than the siltstone spoil. Levels of exchangeable P did not vary among rock mixes, but the sandstone had a higher level of plant available Mn.

Nutrient availability can also be affected by pH within the range of values encountered in this study (5.7-7.1); however, except for Mn, foliar nutrient levels were not meaningfully different between treatments (Table 5). Mg was significantly higher in the siltstone plots than the sandstone plots (1.6% versus 1.2%). Foliar N, P, K, and Ca levels were not affected by treatment, and along with Mg exceeded the critical foliar nutrient concentrations of 1.2% N, 0.1% P, 0.35% K, 0.12% Ca, and 0.07% Mg which are generally accepted for loblolly pine (Allen 1987). Foliar Fe, Zn, and Na were also unaffected by treatment.

Foliar Mn was strongly affected by treatment, and therefore, strongly correlated (r=.77) with tree growth. Foliar Mn levels in sandstone plots (540 mg kg^{-1}) were 240% higher than siltstone foliar Mn levels (160 mg kg^{-1}). Because of the design of this experiment, it's difficult to determine if this correlation results from a cause and effect relationship, or merely from coincidental correlation. Manganese deficiencies are seldom reported, but there is some reason to suspect that a Mn deficiency may be part of the reason for poorer growth on the siltstone. Mn availability is known to decrease as soil pH increases (Marschner 1986), and the pH of this siltstone is well above normal pH range for loblolly or pitch pine.

On natural forest soils, Mn deficiencies are uncommon for pines, and therefore, sufficiency levels are not well documented. In a review of micronutrients in forest trees, Stone (1968) listed Mn levels of 300-400 mg kg^{-1} as intermediate in the range for loblolly pine. His values are intermediate to the range of concentrations encountered in this study (160-540 mg kg^{-1}), which provides some reason to believe that the foliar levels in the siltstone treatment may be deficient. In a parallel study to this experiment, Moss et al. (1989) reported very poor hybrid pine growth on a 2:1 SS:SiS spoil mix as a result of a Mn deficiency where a high soil pH and high organic matter content in sewage sludge-amended minesoils resulted in foliar Mn levels of less than 100 kg ha^{-1}.

Jokela et al. (1991) reported a fertilizer response (2.2 m^3 ha^{-1} yr^{-1} for five years) for slash pine (*Pinus elliottii*) on a Florida spodosol. Trees in their control plots had an average foliar Mn concentration of 48 mg kg^{-1} which was increased to 199 mg kg^{-1} with application of 26 kg Mn ha^{-1}.

Conclusion

This study shows that physical and chemical properties that can vary among spoil types can affect tree growth. These results have been observed to persist through age ten and it seems apparent that mine spoil effects will last at least for one pine rotation.

Results of this study are most meaningful when they are compared with results of a parallel study with forage production (Table 6). On the same rock mix study, Roberts et al. (1988) found production of Kentucky-31 tall fescue (*Festuca arundinacea* Schreb) was greatest in plots predominantly comprised of siltstone. These data illustrate the importance of making a land-use specific choice when choosing a topsoil substitute. Long-term forest productivity may be sacrificed if a topsoil substitute is selected for its ability to accomplish short-term objectives. On reclaimed forest land, it's necessary to establish enough cover to reduce erosion, but considering trees will provide the long-term ground cover and erosion control, the topsoil substitute should be selected to favor trees.

This study in itself can't be used to conclude that sandstone is always a better topsoil substitute material than siltstone. Different sandstone strata may differ from each other more than these two spoils. However, results of this study in conjunction with results of subsequent studies in this area (Torbert et al. 1988, 1995; Andrews 1992), and observations of many mining operations has led to the conclusion that sandstone in general is a good spoil for tree growth. In particular, oxidized sandstone spoils derived from many different geologic formations in the coalfields of Virginia, southern West Virginia, and much of eastern Kentucky are good overburden materials for trees. These yellowish-brown colored sandstone spoils, which often exist immediately beneath the soil surface, usually have a pH of approximately 4.5 to 5.5 and low levels of soluble salts (less than 1 dS m^{-1}), which is typical of natural forest soils in the region. They fragment easily during the blasting process and decompose rapidly after being replaced at the surface. Within several years, many clods of hard rock can be crumbled into a loamy sand soil.

When oxidized sandstone is present, it lies close to the surface before mining.

Hence, it is relatively easy to handle oxidized sandstone separately from underlying strata and replace it at the surface. A benefit to using this 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 reducing the overall coarse fragment content and increasing the water holding capacity. Furthermore, it contains a pool of seed and micro-organisms that can give rise to many plant species that might otherwise remain absent (Davidson and Pollio 1991; Wade 1989). Also mixed in this blend of soil and rock are roots from hardwood species that often become established by sprouting. 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*), red maple (*Acer rubrum*), birch (*Betula* spp), sassafras (*Sassafras albidum*), pines, and other species become naturally established on oxidized sandstone spoils.

Despite the obvious and demonstrated advantages for using the oxidized sandstones as a topsoil substitute in the southern Appalachian region, operators commonly bury the oxidized sandstone 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. Oxidized sandstone often supports good grass growth for a year or two, but the initial effect of fertilizer diminishes and ground covers are sparse by the fifth year. The oxidized iron that gives oxidized sandstone it's characteristic color leads to a lower pH and higher phosphorus-fixing capacity than many siltstones. Because most trees are adapted to acid soils and have a mycorrhizal association that enables them to extract phosphorus from iron-phosphates, they grow better in the oxidized sandstone than grasses and legumes.

Examples of excellent tree growth on oxidized sandstone are common. The best growth encountered in soil-site studies conducted by Tuladhar (1986) and Andrews (1992) occurred in spoils derived from oxidized sandstone. In another study conducted by Torbert et al. (1995) in West Virginia, an oxidized sandstone spoil was selected for installation of an experiment to demonstrate the potential for white pine growth on a soil specifically reclaimed to achieve a productive forestry land use. After 5 years, some trees were more than 3 m tall, and observations at age eight were used to determine that SI was more than 30 m (100 ft).

Considering the tree growth potential that exists on sandstone spoils in the southern Appalachians, regulations regarding selection of a topsoil substitute should be interpreted to require use of oxidized sandstone when possible. Additionally, as data from the next chapter will show, spoil should be placed in a loose condition so trees can fully benefit from the opportunities provided by a desirable growth medium.

Table 1. Effect of minesoil site index (SI_{50}) on potential white pine harvest yield and value after 30 years (from Probert et al. 1992).

Site Index - m-	**Harvest Volume**[1/] MBF/ha	**Harvest Product**	**Harvest Value** ($/ha)
20	18	pulpwood	442
24	35	mixed	2623
30	79	sawtimber	5950

[1/] from Balmer and Williston (1983); MBF is thousand board feet, International 1/4 inch log rule.

Table 2. Survival and growth of pitch x loblolly hybrid pine after five years as affected by mixture of overburden spoil.

Rock Mix Treatment	Survival	Height	Diameter	Volume
	- % -	- m -	- cm -	- cm^3 -
Sandstone (SS)	96	3.6 a	8.6 a	1858 a
2:1 SS:SiS	88	3.5 a	8.6 ab	1577 a
1:1 SS:SiS	88	3.0 b	7.7 b	1065 b
1:2 SS:SiS	90	2.9 b	7.3 b	949 b
Siltstone (SiS)	92	2.2 c	5.4 c	382 c

Values within a column followed by different letters are statistically different according to Duncan's Multiple Range Test at the 0.05 level of probability.

Table 3. Selected physical properties of minesoil (0-20 cm) as affected by mixture of overburden spoil.

Rock Mix Treatment	Whole-soil coarse fragment content	Fine-earth particle size distribution			Whole-soil water retention
		Sand	Silt	Clay	
	- - - - - - - - - % - - - - - - - - - -				g kg^{-1}
Sandstone (SS)	52 b	74 a	14 d	12	43 a
2:1 SS:SiS	57 ab	71 ab	18 c	11	45 a
1:1 SS:SiS	64 ab	68 bc	20 b	12	39 a
1:2 SS:SiS	63 a	64 c	23 ab	13	37 ab
Siltstone (SiS)	74 a	57 d	30 a	13	24 b

Values within a column followed by different letters are statistically different according to Duncan's Multiple Range Test at the 0.05 level of probability.

Table 4. Selected chemical physical properties of minesoil (0-20 cm) as affected by mixture of overburden spoil.

Rock Mix Treatment	pH	Electrical Conductivity	Exchangeable Nutrients P	K	Ca	Mg	Available $Mn^{1/}$
		$dS\ m^{-1}$	- - - - - - - - - mg kg^{-1} - - - - - - - - -				
Sandstone (SS)	5.7 c	0.4 d	47	49 c	435 d	162 b	216
2:1 SS:SiS	6.2 b	0.7 c	56	62 b	548 c	206 a	194
1:1 SS:SiS	6.4 b	0.7 c	53	60 b	562 c	215 a	185
1:2 SS:SiS	6.6 b	0.9 b	51	63 b	666 b	220 a	164
Siltstone (SiS)	7.1 a	1.3 a	42	73 a	777 a	227 a	115

Values within a column followed by different letters are statistically different according to Duncan's Multiple Range Test at the 0.05 level of probability.

1/ from Daniels and Amos (1984). Available Mn was defined as NH_4OAc exchangeable Mn plus easily reducible Mn; statistical comparison of treatments was not possible.

Table 5. Nutrient concentrations of pitch x loblolly hybrid pine at age three years as affected by mixture of overburden spoil.

Rock Mix Treatment	Foliar Nutrients					
	N	P	K	Ca	Mg	Mn
	- - - - - - - - - - $g\ kg^{-1}$ - - - - - - - - - -					$mg\ kg^{-1}$
Sandstone (SS)	15.6	1.3	4.4	2.3	1.2 b	540 a
2:1 SS:SiS	15.9	1.3	4.8	2.3	1.3 b	300 b
1:1 SS:SiS	16.3	1.3	4.7	2.3	1.3 ab	270 bc
1:2 SS:SiS	16.6	1.4	4.7	2.4	1.4 ab	210 bc
Siltstone (SiS)	16.4	1.4	4.6	2.6	1.6 a	160 c

Values within a column followed by different letters are statistically different according to Duncan's Multiple Range Test at the 0.05 level of probability.

Table 6. Comparison of tree production and forage production at age five as affected by mixture of overburden spoil (from Torbert et al. 1990 and Roberts et al. 1988).

Rock Mix Treatment	**Tree Volume**[1/] - cm^3 -	**Forage Production** - $Mg\ ha^{-1}$ -
Sandstone (SS)	7269 a	3.9 ab
2 SS : 1 SiS	6936 a	3.9 ab
1 SS : 1 SiS	4972 a	2.9 b
1 SS : 2 SiS	4259 b	4.4 a
Siltstone (SiS)	1783 c	4.2 a

[1/] 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.

MINESOIL CONSTRUCTION: INFLUENCE OF GRADING INTENSITY ON HERBACEOUS GROUND COVER, EROSION, AND TREE ESTABLISHMENT

For years, reclamation throughout the southern Appalachians has been conducted in a fashion which created a "golf course appearance" by making a smooth landscape 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 to a forestry land use. For an agricultural land use, the land needs to be smooth enough to use farm equipment. Smooth land, however, is not necessarily desirable for managed forest land, and the creation of smooth land during reclamation leads to compaction caused by heavy equipment. Forests typically have rough surfaces strewn with rocks, depressions, and woody debris.

SMCRA does not explicitly require the intensive 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 post-mining slope that does not exceed the angle of repose ..., 4) minimize erosion ..., and 5) support the approved post-mining land use.*" This underlined requirement suggests that grading practices should be land-use specific. When forestry is the post-mining land use, level and gently sloping land (where erosion hazard is slight) should be less intensively graded.

Following a 30-year assessment of tree plantings on graded and ungraded spoil in Ohio, Larsen and Vimmerstedt (1983) concluded that spoil compaction was the most important SMCRA-related problem in need of solution for forest-land reclamation. Other researchers have voiced concern that SMCRA encourages excessive spoil grading that results in growth limiting levels of compaction. Soil compaction increases soil strength, decreases soil aeration and water infiltration, and increases surface runoff. Compacted soils are difficult to plant trees on, seedling mortality is often high, and surviving trees have slower growth rates.

Causes of compaction

Compaction is caused during several steps of the reclamation process. One step is during the placement of a final lift of overburden in the landforming stage of reclamation. 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 1992). The compactive forces from the tracked equipment working on the slope are not directly perpendicular to the surface of the slope and therefore not as compressive as equipment working on level land.

Minesoil placement can cause severe compaction on level areas where the final lift of overburden or topsoil substitute is dumped by trucks and leveled with bulldozers. Sometimes, as trucks arrive with spoil to unload, they drive over the area that was just leveled, they dump new material at the edge of the area, and the material is then leveled by the bulldozer. Thus, dumping and grading occur simultaneously and the surface layer of minesoil becomes extremely compacted from the traffic.

After the landforming stage 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*", "*tracked-in*", or "*trammed*" 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.

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, Larsen and Vimmerstedt (1983) found that yellow-poplar height and diameter were 142% and 67% greater after 30 years on ungraded versus 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*) 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 (1990) compared the survival and growth of six commercially important tree species planted on two adjacent slopes, each comprised of the same spoil material. One was operationally regraded and tracked-in, and the other was left in a rough-graded condition. After two years, tree survival averaged 42% on the conventionally regraded site and 70% on the rough-graded slope. For some species, average height growth was almost doubled by eliminating the compacting process. The study was destroyed in the middle of the third growing season by remining. The trees were not measured after age two, but it was inferred that the effects would have been even greater if measured after three years.

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 trees in compacted soil. Handplanting 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.

Surface grading effects on erosion

Rough graded sites are less prone to erosion since the loose soil has a higher infiltration rate (Merz and 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 that ensures that better vegetative cover will be capable of further protecting 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.

Objectives

The specific objectives of this study were to:

1) compare the influence of three surface grading treatments on erosion. The treatments are i) standard intensive grading, ii) a moderate level of grading, and iii) intensive grading followed by ripping.

2) compare the influence of these three surface grading treatments on herbaceous ground cover development.

3) compare the influence of these three surface grading treatments on survival and growth of five tree species: white pine, loblolly pine, sycamore (*Platanus occidentalis*), sweetgum (*Liquidambar styraciflua*), and yellow-poplar.

Methods

Site Selection and Treatments

The study is located on land mined by Martiki Coal Corp. near Lovely, KY. A slope, approximately 50 m (upslope) by 500 m (along the contour) had been reconstructed and moderately graded to its final contour (40% slope). The site was not topsoiled. The topsoil substitute was an alkaline spoil derived primarily from gray siltstone with a minor component of gray and oxidized sandstone. Spoil pH before hydroseeding ranged from 7.7 to 8.8. Martiki preferred to place this overburden material on the surface because experience proved it was conducive to the establishment of an herbaceous ground cover. The site was awaiting final surface grading and hydroseeding when it was selected for study in January 1991.

The slope was divided into nine plots (50 x 50 m) that were used for three replications of three grading treatments. The three grading treatments, installed on March 26, 1991 were:

<u>Intensive grading</u>. This treatment was the standard operational practice used by Martiki and other operators in the region. Bulldozers (D-9 Caterpillars) smoothed the slopes by backblading (dragging their blades as they backed downhill), afterwhich the surface was tracked-in by running the bulldozer up and down the slope until the entire surface was covered with indentations from cleats on the bulldozer treads.

<u>Moderate grading</u>. For this treatment, no further grading was applied. Grading already completed when the study site was selected resulted in a fairly smooth surface, although some rocks and rills were present. A hard crust was present at the surface since six months elapsed between the time of grading and seeding.

<u>Ripped</u>. This was an ameliorative treatment intended to mimic the surface conditions that might be created by rough-grading. The initial study design called for a rough grading treatment where the slope would be returned to its approximate original contour with a

minimal amount of grading, leaving some boulders, depressions, and loose soil at the surface. Unfortunately, when selected, the study site was already graded to the moderate level. The decision was made to backblade and track-in these plots to the intensive level of treatment, and then ameliorate the compaction by ripping with a 1-m deep subsoiling shank pulled directly downslope by the D-9 bulldozers. Rips were created at 3-m (10 ft) intervals. Ripping created a very rough surface in the immediate vicinity of the rips. Some large boulders (> 1 meter) were pulled to the surface and some deep holes were opened. This treatment did not loosen the entire soil; approximately 1.5 m between the rips remained compacted and unaffected by ripping.

Tree Planting

Trees were planted on April 1 and 2, less than one week after installation of the grading treatments. Five species of trees were planted: white pine, loblolly pine, yellow-poplar, sweetgum, and sycamore. Approximately 40 of each pine species and 20 of each hardwood were planted in each plot on a 3 m x 3 m (10 ft x 10 ft) spacing. Two rows of each hardwood species and four rows of each pine species were planted. All species were 1-year-old seedlings except white pine which were 2-years-old. Trees in the ripped plots were planted in or very near the rip. After the fifth growing season, tree heights were measured and survival was determined.

Ground Cover Establishment

On April 16, two weeks after tree planting, a "tree-compatible" ground cover was established by hydroseeding with a seed mixture similar to that discussed in the next Chapter. After the first and fifth growing seasons, three 30 m (100 ft) transects were installed along the contour of each plot, approximately one-fourth, one-half, and three-fourths of the distance from the bottom to top of the slope. At 0.6 m (2 ft) intervals along the transect, a 2.5 cm sighting tube was used to assess ground cover. If more than half the area observed through the tube consisted of bare soil, the point was tallied as such. If more than half the area was vegetated, the vegetation was tallied as grass or legume. This was done at 150 points per plot.

Erosion Measurements

Soil movement from the slope and deposition at the toe of the slope were monitored by measuring the changes in the distance between the soil surface and the top of metal rods installed in each plot. Three rows of metal rods were installed along the contour of each plot, approximately one-fourth, one-half, and three-fourths of the distance from the bottom to top of the slope. Ten rods were installed in each row, 3 m (10 ft) apart from each other. The above-mentioned vegetation transect was conducted along these rows of rods. A row of measurement rods was also placed at the toe of each plot on the level area. Rods were measured in October 1991, and October 1993, after the first and third growing season.

Results

The study was conceived with the goal of quantifying the amount of erosion and the response of herbaceous and woody vegetation to rough grading on a minesoil with desirable chemical properties for tree growth. Unfortunately, the ripped treatment did not accurately imitate rough grading because the area between rips was still compacted and the area within the rip was rougher than desired. The objective of rough grading is to leave an uncompacted surface that is similar to the surface of natural forest land with respect to undulations of the surface and the presence of rocks and boulders on the ground.

The ripped treatment in this study represented what many people would consider to be a worse-case scenario. If rough grading were likely to increase erosion, then deep ripping directly up and down a steep slope would surely represent a worse case opportunity for erosion to occur.

Although oxidized sandstone spoil is the best medium for tree growth, and it existed at this mining site, it was not possible to find a suitable experimental site where oxidized sandstone was placed at the surface. Unlike most coal operators in the southern Appalachians, Martiki's spoil handling is mostly done with a dragline. As such, the spoil that exists closest to the surface (oxidized sandstone) is placed immediately at the bottom of the adjacent, previously mined pit. In this situation, the best overburden for trees is buried about 20 m below the surface, and the spoil that exists immediately above the last coal seam will almost always end up on the final surface. For operations such as this, where the desired overburden material for forest productivity is not economically available, the challenge exists to develop alternative reforestation strategies. The hardwood species used in this experiment were selected to evaluate their performance on near-neutral pH minesoils.

Ground Cover Establishment

All plots had a southerly aspect, which combined with the dark gray color, resulted in high surface temperatures during the summer in the first year. The site received no rainfall from July to September. Rainfall in June occurred as thunderstorms. Ground cover was very sparse during the first summer because of the dry weather. Average ground cover after the first year was only 44% and unaffected by grading treatment. After five years, average ground cover increased to 86% and was still unaffected by treatment (Table 7). Most of the ground cover during the first three years was provided by weeping lovegrass (*Eragrostis curvula*), a heat-tolerant species. On some of the moderate and intensively graded plots, weeping lovegrass was almost the only species at the end of the first growing season. Although it is generally considered to be an acid-tolerant species (Vogel 1981) it survived very well on this dark, droughty, alkaline spoil.

Average legume cover was only 12% after the first year and 61% after three years. Birdsfoot trefoil (*Lotus corniculatus*) was the predominant legume species during the first three years, but crownvetch (*Coronilla varia*) was the most common after the fifth year.

For the most part, ground cover on the moderately and intensively graded treatments was uniformly distributed across the plot. On ripped plots, however, values in Table 7 are a weighted average of the relatively sparse vegetation that existed in the area between rips and the relatively vigorous vegetation that existed within the loose soil of the rips. Within a 1-meter band up the rip, ground cover was 100%.

Minesoil erosion

Compaction on intensively graded plots increased surface runoff. During a thunderstorm in June of the first year, surface runoff was observed flowing off the slope at the base of the intensively graded plots. On the ripped plots, there was overland flow occurring on the compacted soil between individual rips, but within the rips and immediately adjacent soil disturbed by ripping, water was absorbed into the soil and no overland flow occurred. No water flowed from the rips at the bottom of the slope.

Rips did not develop into gullies during the course of this study. The surface roughness created by ripping diminished over the course of this study as soil next to the rip moved into the rip and collected.

Erosion was quantified by two approaches: 1) as the average depth of spoil lost from the 30 erosion rods on each plot, and 2) by the average deposition at the erosion rods at the base of the plot (Table 8).

After the first growing season, erosion, based on measurements from erosion rods in the treatment plots, was 18 times greater in the intensively graded treatment than in the ripped treatment, and almost twice as high as the moderate-graded treatment. Variability among treatment replicates was so variable that these differences were not statistically different.

Erosion results from third year measurements are confusing and probably unreliable. They indicate that no erosion occurred during the course of the study and that soil moved onto the slope since year one. Measurements of the rods indicate a net deposition of approximately 0.4 cm on the slope in the ripped and moderate graded plots and no deposition or erosion from the intensively graded plots. Of course, these results are not realistic. Perhaps some loosening or swelling of the soil occurred as a result of freezing in the winter which created the illusion of deposition.

Erosion appraisal based on a measurement of deposition at the base of the slope seems to be a more meaningful assessment, although there are still some unexplainable effects between the first and third years. If soil freezing and expansion confounded results on the slope, it would also affect results at the base of the slope. After the first growing season, apparent deposition at the base of the intensively graded plots was about 130% greater than the ripped treatment, and almost 600% greater than the moderately graded treatment. After three years, deposition at the base of the intensively graded plots was about 20% greater than the ripped treatment, and 118% greater than the moderately graded treatment.

This method of measuring erosion does not provide an opportunity to calculate the Mg ha^{-1} of soil movement from the slope with any scientifically responsible level of confidence. Results are still valid however for accomplishing the fundamental purpose of this study. It is possible to conclude that intensive grading did not prevent or decrease the amount of erosion compared to the treatments with looser soil. It's obvious that the intensively graded treatment had as much or more erosion than the moderate or ripped treatments. These results should help dispel the idea that intensive grading is beneficial for reducing erosion.

Tree survival and growth

The study includes two species of pines (white and loblolly) and three hardwood species (sycamore, sweetgum, and yellow-poplar). It was known beforehand that the pH would be undesirable for pine growth, and thus the hardwood species were included. They were selected because of their reported ability to tolerate neutral-pH to slightly alkaline soils (Vogel 1981).

As anticipated, the pine species suffered on this minesoil (Table 9). Only 3% of the white pines survived to the fifth year. Almost all of the loblolly pines appeared dead within two months of planting as foliage on almost all trees turned brown, but regrowth occurred and by age five, 29% were still alive. The surviving loblolly pines were healthier than white pines, but still not vigorous. Foliage on loblolly pines was yellow, and some trees displayed reddish coloration at the tips of needles, suggesting high soluble salt concentrations. The overall poor general health of these trees did not provide a good opportunity to evaluate the effect of these grading treatments on pine growth. Nonetheless, the height of loblolly pines was significantly lower on the intensively graded treatment than the moderate graded and ripped treatments.

Sycamore performed better in this study than any other species, and because it was relatively tolerant of the minesoil chemical conditions, it provides the best demonstration of compaction effects on survival and growth. In the ripped and moderate graded treatments, sycamore survival averaged 70%, but in the intensively graded treatment, survival was only 50%. Growth followed the compaction gradient created by treatment; best growth occurred on the ripped treatment. Compared to the intensively graded treatment, average height was about 34% higher in the moderate treatment, and 74% higher in the ripped treatment.

Survival of sweetgum and yellow-poplar was significantly greater in the ripped versus intensively graded treatment. Only 3% of yellow-poplar survived in the intensively graded plots whereas almost 70% survived in the ripped plots. Growth of yellow-poplar was increased about 78% by ripping, but even in the ripped treatment, growth was not good for yellow-poplar or sweetgum, presumably because of the high pH. Even though these species are tolerant of a high pH, they would grow better in minesoils with a pH more typical of natural forest soils.

Conclusions

The experiment did not include a treatment that fairly represented conditions that would be created by rough grading, that is leaving the soil in a loose condition. The ripped treatment was an ameliorative treatment that mimicked rough grading to some extent, but not exactly. Ripping did not loosen soil between the rips, and the loose soil in and immediately adjacent to the rip was much rougher than would result from a genuine rough grading treatment. The ripping process pulled some boulders (more than one meter in diameter) to the surface, creating huge depressions and open chasms that could be hazardous to people walking on the site.

Even though this study does not provide the opportunity to quantify the beneficial effect of a rough graded oxidized sandstone, it is useful for concluding that the intensively graded treatment, which represents the standard operating practice for most coal operators in the Appalachians, did not provide any improvements in erosion control, ground cover establishment or tree survival and growth. In some respects, the ripping treatment serves as a treatment that provides the opportunity to assess a worse-case scenario. The study was installed on a steep slope where erosion potential was high. The rips were oriented directly upland down the slope which would provide the maximum opportunity for erosion to occur. The fact that ripping did not result in gullies or any observable increase in erosion provides evidence that the presence of loose soil does not lead to increased erosion.

Other researchers have found ripping to be beneficial to improving tree rooting and growth, and have recommended ripping as a standard practice where trees are planted on minesoils (Josiah and 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 which, if necessary to achieve decent tree survival and growth, would discourage operators from selecting forestry as a post-mining land use. Furthermore, ripping can create hazards by uplifting large boulders and creating holes that could be dangerous for anyone walking on the site.

Preventing compaction during post-SMCRA reclamation

Compaction that occurs during placement of the final lift of overburden can be avoided in some cases 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, similar to the manner in which the previously discussed rock mix study was graded. The operator can create a looser, more productive soil and save a considerable amount of money by reducing the amount of bulldozer work. After land shaping, any further grading preceding seeding should be minimal and tracking-in should be avoided, especially on level areas and gentle slopes where erosion potential is slight. It has been estimated that operators in the Appalachians could save about \$500 ha^{-1} on surface grading costs by deliberately constructing minesoils conducive for tree growth (Torbert et al. 1994).

Table 7. Ground cover (%) after five years on a reclaimed minesoil in Kentucky as affected by grading treatment.

Grading Treatment	**Total Cover (%)**		**Legume Cover (%)**	
	average	range	average	range
Moderate	90	71-100	68	42-92
Intensive	85	62-97	61	33-81
Ripped	83	68-95	54	36-82

Table 8. Average soil loss and deposition after the first and third growing seasons on a reclaimed minesoil in Kentucky as affected by grading treatment.

Grading Treatment	**Soil Loss from Slope** (cm)		**Soil Deposition at Base** (cm)	
	Year 1	Year 3	Year 1	Year 3
Moderate	.44	-.39	0.50 b	0.85
Intensive	.72	0.0	3.48 a	2.21
Ripped	.04	-.38	1.51 ab	1.84

Values within a column followed by diiferent letters indicate a statistically significant difference according to Duncan's Multiple Range Test at a probability level of 0.10.

Table 9. Survival and height of five tree species after five years on a reclaimed minesoil in Kentucky as affected by grading treatment.

Tree Species	Ripped		Moderately Graded		Intensively Graded	
	Survival - % -	Height - cm -	Survival - % -	Height - cm -	Survival - % -	Height - cm -
White pine	2	42	7	51	0	--
Loblolly pine	43	99 ab	32	120 a	15	64 b
Sweetgum	74 c	61	41 b	83	39 b	52
Yellow-poplar	69 a	79 ab	38 b	99 a	3 c	44 b
Sycamore	77 a	142 a	63 ab	109 ab	50 b	82 b

Values for survival and height within a species/grading treatment combination followed by different letters indicate a statistically significant difference according to Duncan's Multiple Range Test at a probability level of 0.10.

REVEGETATION: TREE-COMPATIBLE GROUND COVERS AND TREE ESTABLISHMENT

Next to compaction problems, the greatest hindrance to successful tree establishment is 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*" (Section 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 post-mining 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*" (Section 816.111). Furthermore, "*the reestablished plant species shall be compatible with the approved post-mining 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 sometimes lime. Kentucky-31 tall fescue, red clover (*Trifolium pratense*), crownvetch, and yellow sweetclover (*Melilotus officinalis*) are commonly used. Again, this is a logical revegetation strategy for hayland/pasture, but not for forest land. These herbaceous species are not a natural component of forest ecosystems and they often interfere with tree establishment and native plant species (Wade and Thompson 1990). It can easily be argued that their use contradicts the underlined provisions of the above-cited regulation. Herbaceous ground covers can compete with tree species for light, nutrients, and soil moisture, and perhaps directly antagonize some tree species via allelopathy (Walter and Gilmore 1976, Todhunter and Beineke 1979). In some areas, the dense herbaceous vegetation provides cover for rodents that girdle seedlings.

Application of herbicides around tree seedlings has been demonstrated to help tree establishment (Ashby, 1990; Davidson 1984; Philo et al. 1983; Schoenholtz and 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 unsown strips in which to plant trees (Vogel 1980, Washburn et al., 1994). This technique works well on land sown by tractor, but it's not relevant to rugged terrain revegetated by hydroseeding.

Tree compatible ground covers

The concept of a tree-compatible cover was discussed by Plass (1974), Larsen and Schwarz (1980), and Vogel (1980, 1981). In the southern Appalachian region Tackett and Graves (1983) suggested the establishment of oaks by direct seeding could be improved if the herbaceous ground cover consisted of short species such as perennial ryegrass (*Lolium perenne*) and birdsfoot trefoil.

Preve (1983) investigated tree-compatible ground covers in Virginia, and he determined that perennial ryegrass and birdsfoot trefoil were good species for use with trees. Red fescue (*Festuca rubra*) was discouraged because it seemed to have an allelopathic effect on young pine seedlings. Preve also reported that nitrogen fertilization rate was an important determinant of the effectiveness of a tree-compatible cover. Based on a study that involved fertilizer rates of 0, 60, and 120 kg N/ha, he determined that the highest rate of nitrogen did not produce more measurable ground cover, but it did increase ground cover height and competitiveness and decreased tree establishment. Several other unreported pilot studies were conducted that eventually led to the publication of a Powell River Project extension bulletin, *Reforestation Seed Mixtures for Hydroseeding Reclaimed Mined Land* (Torbert et al. 1986).

The challenge to producing a successful tree-compatible ground cover is to produce enough cover in the first year to stabilize the soil and satisfy regulatory requirements, without excessively competing with tree seedlings. Furthermore, a tree-compatible cover provides a beneficial role in the succession of plant species and development of a nitrogen cycle. A tree-compatible cover should include species with the following traits: 1) some rapid germinating species must be included to provide initial erosion control, 2) species must be tolerant of minesoil conditions created for the purpose of achieving good tree growth, 3) the cover should consist predominantly of grass and legumes that are short and not likely to severely overtop tree seedlings, and 4) perennial legumes must be included to accumulate biologically-fixed nitrogen for the development of an adequate nitrogen cycle capable of sustaining a healthy forest ecosystem.

A tree-compatible ground cover provides opportunity for native plants and trees to become established, either from windborne seed or from seed in the seed pool if natural soil was returned as part of the rooting medium. There is an abundance of plant species that will arise from the native seed pool if they are not prevented from doing so by introduced reclamation species (Farmer et al. 1982; Davidson and Pollio 1991). Wade and Thompson (1990) reported that a forest soil seed pool resulted in the establishment of 82 native or naturalized species, including seven tree species, with treatments that did not involve the establishment of a reclamation herbaceous cover. In treatments where a reclamation cover was sown, only three native species survived from the seed pool after two years. In a survey of volunteer vegetation on five pre-SMCRA mined sites in Kentucky (which were not revegetated), Wade and Thompson (1993) found that all sites contained at least one species that was on the Kentucky threatened species list. These studies suggest that a revegetation strategy that favors the establishment of native species is not only supportive of the timber production aspect of a forestry land use, but also supports some of the less tangible benefits provided by a healthy forest ecosystem; in this case, greater plant diversity.

Recommended tree-compatible species. Good success has been achieved in the southern Appalachians by using the seed and fertilizer prescribed in Table 10. Foxtail millet (*Setaria italia*) 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^{-1}), it does not produce a dense cover, but it does produce enough leaf surface area to reduce the impact of raindrops. Foxtail millet should be sowed in the spring when the danger of frost has passed. Since rye (*Secale cereale*) is more frost hardy, it is an appropriate species for autumn seeding (30 kg ha^{-1}). Perennial ryegrass and redtop (*Agrostis gigantea*) are short grass species that will provide good cover in the first year or two. Because they are cool season grasses, they are less competitive during the summer when trees are most susceptible to moisture stress. Kobe lespedeza (*Lespedeza striata* var Kobe) is a short, annual legume, that will provide some first year cover, and it will re-establish itself by seeding if not displaced by more aggressive species.

On steep slopes, orchardgrass (*Dactylis glomerata*) can be included to provide additional protection against erosion. Weeping lovegrass is not a short grass, but it can be a desirable grass species to include at very low rates (2 kg ha^{-1}) on harsh sites. Weeping lovegrass is tolerant of very acid 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 was also 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 first year ground cover in a study where virtually none of the other above-mentioned species survived the first summer (Torbert and Burger 1994). 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^{-1}).

Perennial legumes are important components of the tree-compatible ground cover. Birdsfoot trefoil is a perennial legume that has performed extremely well in many Appalachian studies. Sericea lespedeza (*Lespedeza cuneata*) is not a very desirable legume because it grows tall and presents a fire hazard during the fall and winter. However, a relatively recent variety of Sericea, 'Appalow', is a good choice. Appalow lespedeza tends to sprawl along the ground rather than grow upright, thus it's possible to achieve a dense cover of Appalow lespedeza that may be only about 20 cm tall.

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 first year to be used with trees. An exception is ladino clover (*Trifolium repens*) which is tolerant of acid soils, and grows short enough to be used with trees. When used in combination with birdsfoot trefoil and Appalow lespedeza, ladino clover was found to provide good legume cover for the first two years, and then give way to birdsfoot trefoil and Appalow lespedeza, which formed very dense covers by age five, beneath the stand of established trees.

Fertilization rates

For hayland/pasture, it's common to use nitrogen fertilizer rates of 200 kg N ha^{-1} or more. With tree-compatible covers, it's not necessary to use more than 50-75 kg ha^{-1}. Fertilizer rates of 50-75 kg N ha^{-1} seem to be enough to provide the necessary nutrition to allow vegetation to get established but does not provide enough nitrogen to cause the vegetation to become so vigorous that it overtops seedlings. Furthermore, many legumes will not fix atmospheric nitrogen if soil nitrogen levels are high enough to meet their needs. By using relatively low nitrogen 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. Since phosphorus plays an important role on the N-fixation process, P fertilization rates should be at least 100 kg P ha^{-1} to establish a long-term supply.

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 manipulation by man. 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 nitrogen supply will accumulate with time to supply the continuously increasing demand that trees will have until they reach the stage of crown closure (Jorgensen and Wells, 1987).

Bradshaw et al. (1982) discussed issues related to the development of a nitrogen cycle on mined land. They believe a pool of at least 1000 kg N ha^{-1} must be accumulated, afterwhich nitrogen cycling via mineralization and plant uptake will support a self-sustaining ecosystem. They suggest that the nitrogen capital of the minesoil be supplied by replacing a sufficient quantity of topsoil, adding sewage sludge, or through the use of legumes.

Some forest minesoil amendment research has been conducted to evaluate the effect of sewage sludge and sawdust (Moss 1989), and woodchips (Schoenholtz 1990; Faulconer 1996) on tree growth and nitrogen availability. As would be expected, sawdust and sewage sludge did increase soil nitrogen content (Moss et al. 1989). Sawdust application had the greatest beneficial effect on three-year-old pitch x loblolly hybrid pines even though the effect was probably more related to improved physical properties than increased nitrogen availability. Similarly, nitrogen availability increased with increasing sludge rates (22 Mg ha^{-1} to 224 Mg ha^{-1}), but tree volume (unlike forage production) decreased with increasing rates. Schoenholtz et al. (1992) reported that wood chips increased the early growth of pines, but the growth of trees in the unamended raw rock plots was acceptable, and nitrogen was accumulating in the unamended plots due to nitrogen fixation by the legumes. An important finding of these minesoil amendment studies is that acceptable tree survival and growth occurs without amendments. Although sawdust, wood chips, and low rates of sludge would be beneficial and desirable, they are not necessary and certainly wouldn't be worth spending much money to obtain. Furthermore, competition from grass could become severe with sludge application. The use of legumes capable of fixing large amounts of nitrogen is probably the most practical way to accumulate nitrogen on minesoils.

Based on a chronosequence study of 1- to 30-year-old mined sites, Li and Daniels (1994) estimated a nitrogen 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 nitrogen accumulation rates, mostly on pre-SMCRA sites, were low by comparison with today's practices that utilize other legumes that fix more N. Li (1990) reported that birdsfoot trefoil fixed nitrogen at a rate of 150 kg ha^{-1} yr^{-1} during the first two years on a post-SMCRA reclaimed site. In a controlled lysimeter study with an unamended sandstone spoil and a ground cover similar to Table 10, Schoenholtz et al. (1992) found that 479 kg N ha^{-1} accumulated in the surface 10 cm during the first 2.5 years of the study.

According to Bradshaw et al. (1982), the main period for nitrogen accumulation is the time when legumes dominate the vegetation. On reclaimed forest, the herbaceous legumes will eventually be shaded and succumb to the overtopping trees. The period of nitrogen accumulation can be prolonged, however, by using N-fixing trees and shrubs in the tree planting (Reinsvold and Pope 1985). Nurse trees are often recommended for inclusion on mined land plantings because of their ability to enhance soil nitrogen 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. 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 acid 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.

The use of nitrogen-fixing trees and shrubs may not be as beneficial on post-SMCRA sites as it was on pre-SMCRA sites. Most of the nurse-tree interplanting studies cited in the literature were conducted on sites reclaimed before SMCRA. Most of these sites were probably not seeded with herbaceous legumes, thus the nitrogen-fixing trees and shrubs were primary sources for nitrogen input. On a post-SMCRA minesoil, Brown (1994) found that black locust and black alder did not increase the size of nine-year-old interplanted loblolly pine. These nurse trees did increase soil nitrogen levels, but loblolly pine received adequate nitrogen nutrition without the nurse trees. It is conceivable that the nitrogen supplied by the nurse trees could become more important later in the rotation, and it is likely that other crop tree species that are more nutrient demanding (ie. most hardwoods) would benefit from the nurse trees.

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. 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. If the minesoil is properly constructed and the short-term herbaceous ground cover is not too competitive, trees should be easily established.

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 the landowners as potentially marketable timber. As mentioned, nurse trees increase the supply of soil nitrogen. Nurse trees are usually less expensive to plant and more likely to survive, thus they are important to help 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.

Crop tree selection. 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*), Japanese larch (*Larix leptolepis*), red oak (*Quercus rubra*), and hybrid poplar (*Populus* spp) (Davidson, 1984). In the midwest, many mined sites are capable of growing black walnut, red oak, and yellow-poplar if spoil compaction and herbaceous competition problems are overcome (Davidson 1984). In the southern Appalachians, where minesoil properties are generally more conducive to tree growth, many species will grow.

Shortly after passage of SMCRA, a tree species trial was established on a recontoured mine in Virginia (Torbert et al. 1985). After three years, three pine species (Virginia pine, loblolly pine, and white pine) were growing well and appeared to be practical species for further research. Also in Virginia, Schoenholtz (1983) conducted a study on a pre-SMCRA bench site and a post-SMCRA slope site to study the effect of several cultural treatments in the performance of these three species. At age five, the study was evaluated by Klemp (1988) who determined that all three species were well suited to minesoils and that all species were generally responsive to herbaceous weed control and fertilization.

White pine is commonly planted on Virginia minesoils. The Virginia Division of Mined Land Reclamation (VDMLR), on advice from the Virginia Department of Forestry (VDOF) and the Virginia Department of Game and Inland Fisheries (VDGIF), has urged operators to include white pine in their plantings. As explained by representatives from these state agencies on a Powell River project videotape (*Reclamation with Trees*; Torbert et al. 1992), white pine provides good opportunities for landowners for timber production, and provides an important component to the regional wildlife habitat. On good sites, white pine is unrivaled for its potential to produce sawtimber (Balmer and Williston 1983). Unfortunately, many coal companies have been frustrated by failed efforts to successfully establish white pine seedlings on reclaimed mined land.

Because of problems associated with hand planting seedlings, there has been some interest by coal companies in the ability to establish white pine by direct seeding. It would be convenient for coal companies to sow pine seed via hydroseeder with the ground cover seed, similar to establishment methods for black locust. The use of a tree-compatible ground cover could make it possible to establish white pine by direct seeding. The ease of establishment for black locust is well known, but the establishment of pines appear to be more tenuous. Loblolly pine is relatively easy to establish by direct seeding minesoils (Thor and Kring, 1964; Zarger et al., 1973; Plass, 1974). Preve (1983) experimented with direct seeding pines, and he had good success with loblolly and Virginia pine, but not white pine. The white pine seed germinated, but the seedlings did not survive their first winter. Davidson (1980) also reported that white pine would be difficult and impractical to establish by direct seeding. Other unreported Powell River Project pilot studies have been conducted that further corroborated the above consensus that loblolly pine can be hydroseeded with a reasonable degree of confidence, but white pine cannot.

This experiment was established to further explore the possibility of establishing white pine by direct seeding on minesoil conditions known to be ideal for white pine and in conjunction with a tree-compatible ground cover. Additionally, the study was designed to compare the effectiveness of handplanting versus hydroseeding white pine and black locust, and to evaluate the effectiveness of fertilizer tablets for improving white pine growth.

Objectives

Specific objectives of this study were to:

1) To compare a conventional ground cover seed mixture versus a tree-compatible ground cover mixture, as they affect tree and ground cover establishment.

2) To evaluate the establishment of white pine and black locust by hand planting versus direct seeding.

3) To evaluate the effects of fertilizer tablets on planted pine.

Methods

Study Site

The study was established near Pineville, West Virginia on a 40% return-to-contour slope that had been reconstructed with an oxidized sandstone spoil on the surface. The study site was selected because minesoil conditions appeared conducive to good long-term tree growth. The minesoil consisted primarily of oxidized sandstone. Texture of the soil-sized fraction of this spoil was a sandy loam, the average pH was 4.8, and the electrical conductivity of a 1:5 soil/water (w/w) extract was only 0.3 umhos/cm.

The final surface was rough graded with an experimental variance from the West Virginia Division of Environmental Protection to leave the site without final grading or tracking-in before seeding.

Treatments

The study consisted of two ground cover treatments and three tree-establishment treatments, factorially arranged, and replicated three times. Plot dimensions were 22 x 18.3 m. The two ground cover treatments were: 1) a "conventional" seed mixture (the seed mixture operationally used by the coal operator at this site), and 2) a "tree-compatible" seed mixture (Table 11). Ground cover seed and fertilizer were hydroseeded in early May 1986. Fertilizer was applied as ammonium nitrate, diammonium phosphate, and potassium chloride.

The tree establishment treatments were:

1) Direct seeding white pine and black locust. Seeding rates were 2.24 kg ha^{-1} for white pine and 0.56 kg ha^{-1} for black locust. Tree seed was hand sowed immediately before hydroseeding the ground cover. Pine seed received cold storage treatment for sixty days before application, and black locust seed was scarified by soaking in concentrated sulfuric acid for five minutes (USDA 1974).

2) Hand planting white pine on 3.7 x 3.7 m spacing and direct seeding black locust at a rate of 0.56 kg ha^{-1}. Pines were planted in six rows with five trees per row. The plots were split (three rows per subplot) and half the pines were planted with a 21 g slow-release fertilizer tablet (20-10-15).

3) Hand planting white pine on a 3.7 x 3.7 m spacing, and interplanting black locust on a 3.7 x 7.4 m spacing. Plots were split such that half the pines were planted with a fertilizer tablet.

Trees were planted in April 1986. One-year-old black locust seedlings and two-year-old white pine seedlings for this study were obtained from the VDOF. Pine seedlings were graded such that all seedlings had a stem caliper of approximately 6 mm; smaller and larger trees were discarded. Stem heights ranged from 20-30 cm. Seedling roots were pruned to a length of 20 cm and dipped in a soil moisturizing slurry. Soil moisture levels were good for planting and several days of cool rainy weather followed. Ground cover percentage was measured in October after the first and fifth growing seasons. Line transects were established across the two diagonals of the plot. At 30 cm intervals along the transect, the presence or absence of vegetation was observed through a 2 cm diameter sighting tube. There were 100 observation spots per plot. The spot was considered to be vegetated if more than 50% of the area observed through the tube was covered with plant foliage. During the fifth year measurement, the percent of grass and legume cover was also measured with a sighting tube.

After five years, the number of locust seedlings established by direct seeding was determined by tallying the locusts that occurred within a 1 m band along the ground cover transects. The number of pines established by direct seeding was determined by tallying all pines in the plot. Total height and ground line diameter of planted pines was measured after each growing season for five years.

The effect of ground cover treatment on first and fifth year ground cover percentage was statistically tested by comparing the nine conventional cover plots versus the nine tree-compatible cover plots with a t-test. Similarly, a t-test was used to determine if ground cover treatment had a significant effect on the number of pines or locusts established by direct seeding. The effect of ground cover treatment, locust establishment method, and fertilizer treatment on the survival, height, and diameter of planted pine after five years were tested with ANOVA for a randomized split plot design. Ground cover and locust establishment method were the main effects and fertilizer was the split plot effect. Treatment effects were considered statistically significant if the alpha level was 5% or less, and means separations were determined with Duncan's Multiple Range Test.

Results and Discussion

Ground Cover Treatments

It was hypothesized that the tree-compatible seed mixture would result in a sparser ground cover than the conventional mixture during the first year, and that less herbaceous competition in the tree-compatible treatment would result in better tree establishment. Furthermore, it was anticipated that the tree-compatible ground cover would be more vigorous in the long term since it included more acid tolerant perennial grasses and legumes. In actuality, the tree-compatible cover was sparser during the first year and denser during the fifth year, but the difference was never statistically significant.

After the first growing season, the conventional seed mixture treatment had 87% ground cover and the tree-compatible treatment had 80% cover. After five years, ground cover increased to 95% in the conventional treatment and 100% in the tree-compatible treatment. After five years, the tree-compatible treatment had a significantly greater legume component than the conventional treatment (93% vs 16%), whereas the conventional treatment had more grass (85% vs 53%), predominantly tall fescue.

Appalow lespedeza (*Lespedeza cuneata*) was the dominant legume in the tree-compatible cover, with 92% coverage after five years. It was also the dominant legume in the conventional plots in that it invaded, with an average cover of 9%.

There were no ground cover treatment effects on tree establishment or growth because the conventional cover was not as vigorous as expected initially. The conventional seed mixture used in this study often results in an aggressive ground cover, with fescue and clover overtopping tree seedlings. In this study, it was observed that the first year conventional cover lacked a clover component, even though red clover and yellow-sweet clover were included in the mixture. Presumably, the low pH and high P-fixing capacity of the oxidized sandstone were not conducive to development of a vigorous clover component.

Direct seeded white pine Five years after sowing white pine at a rate of 2.24 kg ha^{-1}, there were an average of 716 white pines ha^{-1}. This is better than any other reported study on Appalachian minesoils, and based on this average, it might appear that direct seeding could be a feasible tree establishment technique. In reality, however, the number of pines was extremely variable (0-1211 trees ha^{-1}) with most plots having zero pines. Only two plots had a meaningful number of pines established. These plots received partial shading during the late afternoon, had more bulldozer tracks than the rest of the study area, and had sparser than average ground cover. These results can be used to hypothesize that tracking-in, despite it's known adverse effects on planted tree survival and growth, may occasionally be beneficial to the establishment of direct seeded trees. It appeared that white pine germination, and survival of the germinants was higher in these plots because of higher surface soil moisture. In a greenhouse study, Preve et al. (1984) found white pine germination and survival to be better in a siltstone spoil than a sandstone spoil (although growth was better in the sandstone), because the finer textured spoil had a higher moisture retention.

White pine was observed to be abundant after germination in all plots, but they were not present the following spring. Presumably they died from frost heaving. On these minesoil conditions, white pines were only several cm tall after the first growing season. The use of higher nitrogen fertilizer rates would probably cause seedlings to grow bigger and be more resistant to frost heaving, but the nitrogen would also stimulate the herbaceous vegetation and shading of the pines could prevent them from surviving the first growing season.

Height of direct seeded trees was not measured, but few if any pines were greater than 50 cm tall. After five years, the tallest direct seeded pines were about as tall as hand planted pines were after two years in the field.

The study confirms the biological possibility of establishing pine by direct seeding, but from a forest management perspective, direct seeding is an unreliable way to establish a well stocked stand. Furthermore, there are few practical advantages to the operator, especially considering the negligible cost difference between sowing seed and planting seedlings. The cost to sow 2.24 kg of white pine seed (\$77 kg^{-1}; \$172.48 ha^{-1}) and to handplant 750 trees ha^{-1} (\$0.25 $seedling^{-1}$; \$187.50 ha^{-1}) were about the same, but the risk with seeding was much higher.

Direct seeded black locust. It is more feasible to hydroseed black locust than white pine. Locust is routinely hydroseeded on mine soils because the seed is inexpensive (less than \$10 kg^{-1}) and is readily established by seeding, even in the presence of aggressive ground covers. This study demonstrated the ease with which locust can be established and also the potential to establish too many locusts. Five years after sowing locust at a rate of only 0.56 kg ha^{-1}, there were an average of 2,632 trees ha^{-1} (ranging from 240 to 5,733 ha^{-1}). An excess of nurse trees will compete for site resources with the crop trees and the thorny branches of black locust can cause direct injury to adjacent trees. Based on the desire to establish about 375 nurse trees ha^{-1} (the rate at which locusts were interplanted in this study), the locust should have been sowed at about 70 g ha^{-1} under the study conditions.

Most direct seeded locusts were approximately 1-3 meters tall, and seemed to lag the height of planted locusts by about two years.

Establishment of planted pine

Survival and growth of planted pines was very good (Table 12). Survival averaged 73% and was unaffected by ground cover treatment, locust establishment treatment, or fertilizer treatment. Much of the mortality occurred from deer browsing during the first winter. By age five, most trees were tall enough such that recent deer browse was limited to lateral branches. After five years, average tree height was 1.9 m, and some were more than 3 meters tall. This is much better growth than is routinely encountered on mined land in the region. This study site was included in a survey of 78 reclaimed sites in Virginia and West Virginia where white pine was planted (Andrews 1992), and it was the site where the best growth occurred. Andrews attributed the excellent growth to physical and chemical characteristics of the uncompacted, oxidized sandstone spoil in this study.

The use of a tree-compatible ground cover or fertilizer tablets did not significantly increase the five year height or diameter of planted white pines, but there was an effect of locust establishment on pine diameter (Table 12). Average pine diameter was significantly reduced by the excessive number of direct seeded locusts. During a visit to the site in 1993 when the trees were eight years old, many of the pines were overtopped and suppressed by seeded locusts.

Conclusion

The results of this study can be extrapolated to other sites in the southern Appalachian region with similar minesoils. On uncompacted, acidic minesoils similar to this study site, ground cover species selection is not crucial to tree establishment. Oxidized sandstones are widespread throughout the region, but they are often deliberately buried beneath other overburden because coal operators have recognized that some of the higher pH spoils result in better initial ground cover. On minesoils with a near-neutral pH, the difference in competitiveness of the tree-compatible cover and the conventional cover may be more pronounced, and the tree-compatible cover may be more appropriate if trees are planted. Thus when oxidized sandstone is selected, competition problems are not as likely to be severe, and coal operators may not need to use a tree-compatible cover. On the other hand, operators may choose to use the tree-compatible cover, primarily for the purpose of increasing the likelihood that they will have sufficient ground cover at the end of the bond period. The herbaceous species in the tree-compatible ground cover were better suited to these minesoil conditions that many of the species in the traditional cover mixture.

This study showed that, on a properly created minesoil, good white pine survival and growth can result without special consideration of ground cover species or the use of fertilizer tablets. A commercially useful white pine plantation can be established by planting trees on a 3.7 x 3.7 m (12 x 12 ft) spacing and either interplanting or spot-sowing black locust on a 3.7 x 7.4 m (12 x 24 ft) spacing or hydroseeding locust seed at a rate of about 70 g ha^{-1}. A practical alternative to either handplanting or direct seeding black locust is spot seeding at specific locations. Several seeds can be placed at the desired location, thus providing control of the locust spacing without incurring the entire expense of planting, and it is a way to keep the height growth of the locusts somewhat delayed.

Table 10. Species and fertilizer recommendations for a tree-compatible ground cover on oxidized sandstone soils in the southern Appalachians.

Species	Application Rate kg ha^{-1}
Grasses	
foxtail millet (*Setaria italica*)	5
redtop (*Agrostis gigantea*)	2
perennial ryegrass (*Lolium perenne*)	2
orchardgrass (*Dactylis glomerata*)	5
weeping lovegrass (*Eragrostis curvula*)	2
Legumes	
kobe lespedeza (*Lespedeza striata* var Kobe)	5
birdsfoot trefoil (*Lotus corniculatus*)	5-10
'Appalow' lespedeza (*Lespedeza cuneata* var Appalow)	5
ladino clover (*Trifolium repens*)	3
Fertilizer	
Nitrogen	50-75
Phosphorus	100

Table 11. Species and fertilizer rates used for conventional and tree-compatible ground cover treatments on a forestry reclamation study in West Virginia.

Species	**Conventional Ground Cover**	**Tree-Compatible Cover**
	- - - kg ha^{-1} - - -	
<u>Grasses</u>		
foxtail millet (*Setaria italica*)		5.6
Kentucky-31 fescue (*Festuca arundinacea*)	37.9	---
perennial ryegrass (*Lolium perenne*)	19.0	5.6
annual ryegrass (*Lolium multiflorum*)	12.9	---
highland bentgrass (*Agrostis tenuis*)	2.2	---
orchardgrass (*Dactylis glomerata*)	12.0	---
redtop (*Agrostis gigantea)*	----	2.2
<u>Legumes</u>		
red clover (*Trifolium pratense*)	9.0	---
yellow sweetclover (*Melilotus officinalis*)	5.4	---
birdsfoot trefoil (*Lotus corniculatus*)	8.2	5.6
'Appalow' lespedeza (*Lespedeza cuneata* var Appalow)	----	11.2
Fertilizer		
Nitrogen	80.6	40.8
Phosphorus	99.7	103.9
Potassium	18.7	61.7

Table 12. Average survival, height and diameter of white pine after five years as affected by various treatments on a forestry reclamation study in West Virginia.

Treatment	First Year	Fifth Year		
	survival (%)	survival (%)	Height (cm)	Diameter (mm)
Locust Establishment Treatment				
Planted	80	78	191	45.3 a
Seeded	77	67	170	39.8 b
Ground Cover Treatment				
Conventional	77	74	187	44.7
Tree-compatible	80	71	173	40.4
Fertilizer Tablet Treatment				
Control	78	71	180	42.2
Fertilized	79	74	180	42.9

1/ Values within a column followed by different letters are statistically different according to Duncan's Multiple Range test at the 0.05 level.

TREE PLANTING GUIDELINES FOR APPALACHIAN MINESOILS

Research presented in the previous three chapters indicates that, under the right circumstances, reclaimed mined land can be as productive for trees as the land was before mining. From this research, extension publications have been written that describe the advantages of commercial forest as a post-mining land use and reclamation considerations for achieving that land use. These are: *Restoring Forests on Surface-Mined Land* (Burger and Torbert 1992) and *Commercial Forestry as a Post-mining Land use* (Torbert et al. 1994). These publications provide important information about the reclamation process; overburden placement, grading practices, and revegetation. There is also a 23 minute videotape, *Better Reclamation with Trees*, available through the Virginia Cooperative Extension Service.

This chapter focuses on the tree planting process. The underlying assumption is that tree planting will serve the combined goals of the landowner and coal operator. Accordingly, there are some important aspects of tree planting that are unique to minesoils, including the very important decisions and steps that need to be taken in the planning and permitting phase.

Objectives to Achieve with Tree Planting

The purpose for tree planting is to establish a community of tree species that will accomplish several things:

1) provide enough stems to achieve bond release for the operator.

2) provides trees of commercial importance that will produce timber for the landowner.

3) replace the natural forest ecosystem with a reclaimed system that has adequate plant diversity, species distribution, visual quality, and wildlife benefits.

Currently, much of the southern Appalachian mined landscape is reclaimed to a wildlife land use and planted with autumn olive, black alder, bicolor lespedeza, black locust and other miscellaneous trees. In Virginia, white pine is commonly included. Members of a planting crew working side by side will each plant a different species. On sites that are two or three years old, it's common to see a row of autumn olive winding across the landscape, parallelled by a row of black alder, and then bicolor lespedeza. Survival of the pines or other crop trees is sometimes poor, or growth is slow, so they will hardly seem present. Next there will be another row of autumn olive, then alder, and so forth. This planting scenario achieves only one of the above-mentioned objectives; stocking requirement for bond release. The predominant species (black alder, autumn olive, and bicolor lespedeza) provide no commercial potential, they are not native species, their planting configuration does not mimic nature, and their actual benefit to wildlife is debatable.

Admittedly, a wildlife post-mining land use does not require the establishment of commercial species. However, in most cases this land use is not designated for any real concern about wildlife habitat, but instead, for the same reasons hayland/pasture was so common in the early 1980s; its easiest to achieve. This species composition of miscellaneous shrubs was not developed as a result of careful consideration by wildlife biologists to improve habitat for any particular game or non-game wildlife species. These trees and shrubs are used because they are inexpensive, easy to establish across a broad range of minesoil properties, and involve almost no risk. Their use for wildlife has been justified because of the seed and berries they produce.

Wildlife habitat consists of more than just food. Landowners that truly wish to improve wildlife habitat can do so in conjunction with commercial forest land. Productive forests automatically provide productive wildlife habitat. Pine plantings provide winter cover for visual and thermal protection. In the southern Appalachians, forests are dominated by hardwoods, and winter cover is relatively scarce. Providing additional sources of cover to the region is probably more important to wildlife than providing additional food. Furthermore, almost all tree species produce seed that can be eaten. Hard mast produced by oak can be especially important for many animals. The short-term benefits provided by using "berry bushes" such as autumn olive can still be acquired in a commercial forestry land use by including these species as nurse species.

Given the current success that operators have achieving bond release criteria with alder, olive, and lespedeza, any alternative planting plan will also have to :

1) provide enough trees to ensure bond release, without...
2) increasing costs above the current costs for tree planting.

This will be challenging because crop trees (especially hardwoods) are generally more expensive, more difficult to obtain (often coming from private nurseries), and less apt to survive. The following guidelines are suggested as a method to achieve the combined objectives of the operator and the landowner.

Mining Permit Development

The mining permit application consists of hundreds of pages that describe the mining and reclamation plans. Only a couple of these pages are related to revegetation. These pages, however, are a very important part of the permit and their contents can have important long term ramifications for future land use.

Reclamation cannot be deemed successful unless it is approved by the inspector. The reclamation inspector's role is to be sure that everything specified in the mining permit is adhered to. Therefore the permit needs to be written to give inspectors the opportunity to accept conditions that are favorable for tree growth, but might look different from past practices. Following are several sections of a mining permit application that should be addressed.

Pre-mining land use. SMCRA mandates that land be returned to its pre-mining land use or a higher use. Much of the surface mined forest land is owned by corporate landowners that have a long-term forest management plan on their property. Furthermore, in states like West Virginia, their land is taxed at a lower rate based on the fact that the land is managed for forestry and a management plan has been recorded. Since this land obviously has a pre-mining land use of managed forest, landowners should insist, and regulators should require that the post-mining land use be commercial forestry. The operator should be required to establish commercial species. Additionally, the operator should have the opportunity to benefit from AOC variances and reduced grading costs.

Post-mining land use. The landowner needs to determine long-term objectives. Large corporations often have several management divisions. It is common for corporations to have a division in charge of coal and gas leases, and another in charge of land and timber management. Those with responsibility for determining the post-mining land use are different from those who manage the property. Commonly, the foresters do not get involved with mined land until after bond release, because this responsibility is the domain of the corporation's mining engineers. Mining engineers, without regard for long-term land use are often motivated to coordinate with the coal operator to ensure that the mining process progresses smoothly. Hence, it has been very common for one faction of the corporation to support the coal operators' decision to replace forests with grass and another faction to complain about the operator's reclamation practices. Productive reclamation of forest land will not occur unless everyone representing the landowner is working to achieve the same long-term goals.

The permit should specify that the post-mining land use is commercial forestry. For example, the purpose of the land use might be to produce white pine sawtimber and provide wildlife benefits. The goal of reclamation is to create a minesoil with a site index (SI_{50}) of 30 m (100 ft). Landowners should confer with the regulatory agency to find out if a management plan is necessary, and if so, what is required. It will probably only require some estimate of time required to harvest and an estimated harvest yield. This information can be obtained with the help of state foresters.

Surface grading. Specify that level areas and gentle slopes will be lightly graded to avoid compaction and final surface roughness will resemble natural forest land. Uncompacted soil is essential to achieve the post-mining land use.

Revegetation: ground cover. Specify that a tree-compatible ground cover (Table 10) will be used to control erosion, facilitate tree establishment, encourage native tree establishment, and develop a diverse plant community that is typical of native forest ecosystems.

Revegetation: trees. If the permit is written such that it provides a lot of flexibility with regard to species selection during planting, the inspector can provide a lot of flexibility. On the other hand if the permit is narrowly worded and specifically lists four species to be planted, then those four trees must be planted. For example, if the list specifies white pine, black locust, autumn olive, and bicolor lespedeza, they all have to be there for bond release. If, for some reason, the operator substitutes Virginia pine for white pine, the inspector can require the operator to either replant with white pine or change the permit. Both are expensive. Bond release can, and has, been denied because one of the trees listed in the permit was not present in a sufficient proportion to satisfy the inspector. The inspector does not have the authority to change the permit. This is done by another part of the regulatory agency. The permit should be written to provide flexibility. An example is as follows:

> *The area will be planted or seeded with at least four species from the following list: white pine, Virginia pine, Norway spruce, white oak, red oak, white ash, green ash, yellow-poplar, red maple, sugar maple,*

sycamore, black locust, bristly locust, black alder, bicolor lespedeza. At any given location, the specific species selection will be based on seedling availability, and in accordance with the suitability of the planting site for each species' site requirements based on spoil type, degree of compaction, ground cover competition, topographic position, and aspect. Some of these species may be established by direct seeding, and some invasion of native species is expected.

Tree Species Selection

Tree planting. In Virginia and most surrounding states, bond release requires 987 trees ha^{-1} (400 stems $acre^{-1}$). To guarantee bond release, approximately 1500 trees ha^{-1} (600 $acre^{-1}$) is a good target planting density. Approximately 500 ha^{-1} (200 $acre^{-1}$) can be expected from sowing black locust seed and natural invasion if a tree-compatible cover is used on a brown sandy minesoil. If Virginia pine or white pine is selected as the crop tree, about 1000 trees ha^{-1} (400 $acre^{-1}$) should be planted. With planting and seeding, this should provide enough stems for bond release. Another 250 miscellaneous trees ha^{-1} (100 $acre^{-1}$) should be planted to guarantee stocking and to provide some diversity and wildlife benefits.

If hardwoods are planted because the site is not conducive to pines or because the landowners prefer hardwoods, 500-750 trees ha^{-1} (200-300 $acre^{-1}$) of several species should be planted.

Direct seeding trees. Direct seeding is an important part of the reforestation strategy because it provides the opportunity to establish many stems for bond release at very little cost. This cost savings is necessary to offset the increased cost of planting some of the crop trees, particularly some of the hardwoods. Black locust is the most reliable species to hydroseed. Historically, the use of black locust has been abused by sowing at excessive rates of 3-5 kg ha^{-1} and producing tens of thousands of trees. The goal is to obtain 400-800 locusts ha^{-1} (150-300 $acre^{-1}$). If a tree-compatible ground cover is used, include 70 g seed ha^{-1} (1 ounce $acre^{-1}$) with the ground cover seed mix. If Kentucky-31 and red clover are used in the ground cover mixture, double or triple the locust rate. Autumn olive and bicolor lespedeza can also be established by direct seeding. There is not enough data available to make a recommendation, but operators can start by applying the same rates as locust and eventually increasing or decreasing rates based on experience.

Post-mining planning. Regulations require trees to have been planted for at least two years before final inspection. Sometimes there is an advantage to waiting until two years before bond release before planting. Waiting defers the cost of planting. It also provides time to determine the success of direct seeding and allows for fine-tuning the number of trees to plant. Also, aggressive ground covers with Kentucky-31 and red clover will usually become less aggressive with time, and after three years the clover may be gone, thereby increasing chances for good survival. This is especially true on brown sandy minesoils. On the other hand, if a tree-compatible ground over is used, trees should be planted early because the ground cover will become more aggressive with time.

As planting time approaches, decide what to plant based on soil/site conditions. For example, if it is obvious that a lot of compacted, gray minesoil is present, don't plan to use white pine. Instead, choose several appropriate species such as sycamore, yellow-poplar, Norway spruce, etc. and place an order with a good nursery as soon as possible. Try to arrange for a good pick-up date, and be sure a reliable tree planting crew will be available when trees should be planted, (December-March).

Species selection The VDOF recommends white pine for mined land planting. White pine can grow very well on some minesoils and in the absence of any strong preference by the landowner, white pine is a good choice. However, landowners who want to grow another species should not be discouraged from doing so. Most pine and hardwood species that are indigenous to the region should grow well, provided all of the appropriate minesoil conditions exist. As described in extension publications, the best minesoils are those that have sandy brown soil, are loose and uncompacted, and don't have a thick herbaceous ground cover. In many cases, these conditions don't exist and other species will be better suited to the minesoil than white pine.

In some cases, the landowner might be interested in growing a specialty forest crop such as Christmas trees or Paulownia. These can be successfully produced on minesoils and Powell River project extension publications are available for help (Torbert et al. 1989; Torbert and Johnson 1990).

Species/site compatibility. There are several soil/site variables that influence tree survival and growth. These variables are spoil type, degree of compaction, herbaceous vegetation, wetness, and slope aspect. Table 13 is a species/site matrix that provides a tolerance rating of various species for different minesoil conditions. For any particular condition, a rating of "good" indicates that the species is more tolerant of the condition than most of the other species, and would therefore be a good choice. A rating of "poor" indicates a distinct non- tolerance, and the species should be avoided. A rating of "fair" indicates an average tolerance. A designation of "good" does not mean the species prefers the condition, but it is merely more tolerant that the other species in the list. For example, white ash (*Fraxinus americana*) does not prefer compacted soils, but experience has shown that it will survive and growth doesn't seem to be as adversely affected as the other crop trees listed (Zeleznik et al. 1993).

Spoil type. Minesoils can be classified into three categories based on their pH: low-pH, moderate-pH, and high-pH. Soil pH seems to represent a suite of chemical properties that influence plant growth (nutrients, soluble salt concentrations, P-fixing capacity, etc.) The moderate-pH soil has a pH of 4.5 to 5.5, a range that is suitable for most tree species and typical of natural soils. In the southern Appalachians, the brown-colored spoils, especially sandstone are moderate-pH soils. The natural occurrence of plant species such as broomsedge, coltsfoot, and lespedeza seems to indicate minesoil conditions that will result in the successful establishment of most tree species. The presence of broomsedge is an especially good site indicator for white pine.

Occasionally low-pH spoils with a pH of less than 4.5 occur. Often, the natural clayey subsoils when recovered and replaced at the surface have a pH of 4.0 to 4.5. Sometimes oxidized sandstones have enough pyrite to produce a pH of 3.5 to 4.5. Brown spoils with a pH of 3.5 to 4.5 seem to be indicated by the presence of volunteer birch (*Betula nigra*) seedlings, red-colored sourwood seedlings, and reindeer moss. Some of the siltstones, especially those immediately adjacent to a coal seam may be extremely acidic. These are often dark gray or black and support little natural vegetation. White precipitates can often be seen on the surface when they have laid idle without rainfall for a while.

High-pH spoils are common in the southern Appalachians. It is common to encounter spoils with a pH of 7.0 to 8.0. These are usually siltstones or calcareous sandstones. Their presence seems to be indicated by a scarcity of any native volunteer vegetation on bare spoil. High pH sandstones seem to decrease in pH more rapidly than siltstone. Within a few years high-pH sandstone may become tolerable to some hardwood species. A species that seems to indicate that pH has decreased to an acceptable level is coltsfoot, that flowers early in the spring with a flower that looks very similar to dandelion's.

The effect of these different spoil pH types on forest productivity is to influence seedling survival and growth. Each tree species has a preferred pH range within which the species must be planted to have a reasonable likelihood of survival. Virtually all native species are tolerant of the moderate-pH spoils. Some hardwood species and Norway spruce (*Picea abies*) are tolerant of the high pH range, although none seem to prefer a high pH versus a moderate pH. Very few species can tolerate a low-pH spoil when pH is less than 3.5.

Compaction. Compaction results from surface grading and other equipment traffic. Compaction is most severe on level area and at the very top of slopes, where bulldozers pivot and turn to start another pass down the slope. Compaction also tends to be more severe on siltstone-derived minesoils than sandstone-derived minesoils. Soil compaction results in decreased rooting volume, increased soil strength, and decreased moisture availability. Furthermore, since tree planters have a difficult time opening holes in compacted soil, they tend to severely root prune the seedlings. Most of the nurse species are relatively tolerant of compaction, as are the ash species.

Herbaceous vegetation. When a traditional reclamation seed mixture is used, herbaceous competition can be severe for tree seedlings during the first few years. The problem is most severe when trees are planted the spring following a fall hydroseeding of annual rye, Kentucky-31 tall fescue, and red clover. The combination of these three species produces a tall, dense ground cover. This ground cover seems to be most aggressive on a near-neutral and high-pH minesoils. As mentioned, these are the spoils that are not very conducive to tree growth and therefore the trees are already somewhat stressed. The cumulative effects of spoil type and competition can be lethal.

Some species are better suited for dense ground covers because the seedlings are taller than the grass. Its possible to get many hardwood seedlings that are 50-100 cm tall, and still relatively easy to plant. Sycamore and yellow-poplar are two examples.

Another option for dense ground covers is to spray herbicide around each seedling after planting. This will be time consuming and expensive, but it may be warranted under some circumstances.

Spoil wetness. This condition is closely related to compaction. Often compacted flat areas allow water to stand. The presence of cattails or puddled soil are indicators. Norway spruce, green ash (*Fraxinus pennsylvanica*), sycamore, and black alder are tolerant of wet sites.

Slope aspect. This is a relatively minor consideration of most importance on steep slopes. Minesoils on north facing slopes will be cooler and moister than southern aspects. Therefore species that are less tolerant of droughty soils should be planted on north slopes, such as sugar maple (*Acer saccharum*). Virginia pine is more tolerant of southern aspects.

Seedling Handling and Planting Techniques

Many attempts to establish trees have failed because of poor planting techniques or due to mishandling of seedlings before planting. Most coal operators rely on tree planting contractors for planting. Many contractors working on mined land do not understand 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.

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 contractors to start looking for a supply of seedlings at the time trees should be planted.

When seedlings are in short supply, the operator may have to settle for less than desirable seedlings. The only obtainable seedlings may be smaller (or larger) than desired, they may have to come from a distant nursery, and they are apt to be more expensive. Seedlings held in cold storage for more than a year may be available from some nurseries at a discount. This can be a tempting offer, especially for contractors. Although the seedlings may appear normal in all respects, there is a good likelihood that they do not have the same root growth potential that seedlings recently lifted from the nursery beds would have. Accordingly, survival can suffer. Good quality planting stock is essential to getting 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 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 condition. If the operator or tree planter does not have cold storage facilities, only a few days supply of seedlings should be accepted from the nursery.

Seedling preparation. There is a tendency for tree planters to excessively prune roots, and some have been known to top prune shoots of hardwoods below the point where there are any live buds on the stem. Some planters have pruned seedlings to the point where death is almost guaranteed. Someone should ensure that pine seedlings are not top pruned at all and hardwoods should not be pruned below the point of live buds. Roots should never be cut to less than 6-8 inches long. During planting, roots must be protected by drying. Water absorbing gels are often used as a root dip to prevent drying in the field before planting.

Planting. Someone should supervise the actual planting operation to make sure that trees are planted on a proper spacing, planted sufficiently deep, and that holes are properly closed. Planting holes should be at least 6 to 8 inches deep, and the seedling should have all of its roots in the hole. If handplanted, planting holes should be made with "dibble bars", and tree planters should be discouraged from using "hoedads". Hoedads, are commonly used for planting on sandy soils in the southern U.S., 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, its probably safe to assume most hoedad planters will make holes that are too shallow on hard or rocky soil.

Microsite selection. On areas being 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 site in accordance with Table 13. For example, if planters were carrying red oaks with large roots, white pines, autumn olives, and black alder, the planter could plant the oak whenever an excellent planting hole in soft soil was encountered. White pine and black alder could be alternated on average spots, and autumn olive could be used on rocky and compacted spots. White ash is a crop tree that seems to be relatively tolerant of compaction. Additionally site selection could be based on slope position, with green ash, sycamore, and black alder being planted at the toe of slopes that are likely to be wetter, and white ash planted further up the slope. Red oak and sugar maple 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 some improvement in traditional practices should be possible.

Supervision. A lack of supervision of tree planting contractors is clearly an important reason for much of the 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's difficult to make a good planting hole, and to see trees planted less than a meter apart from each other on uncompacted minesoils where it's easy to plant trees. It is also not rare for unsupervised planters to put more than one seedling in a hole.

Beyond supervision, it would be desirable to require tree planters to meet specified performance criteria as specified by a contract.

Use of mycorrhizal seedlings

Much has been written about the role of mycorrhizae and tree establishment on harsh sites (Marks and Kozlowski 1973; Marx 1980). In particular, *Pisolithus tinctorius* (Pt) has been important for establishing trees on acidic minesoils (Marx 1975; Marx and 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. Schoenholtz et al. (1984) did not find an increase in survival or growth of three pine species in Virginia. In a subsequent 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 acid 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 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, personal communication) to develop an alkaline-tolerant strain of Pt that could be beneficial for tree establishment on alkaline spoils in the eastern and western United States.

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 sometimes, 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 and Burger, 1984), but they seem to have little or no effect on white pine (Funk and Krauss, 1965; Schoenholtz and Burger, 1984).

Table 13. Species tolerance ratings for various adverse minesoil conditions.

	Minesoil Condition						
Species	**pH < 4.5**	**pH > 6.5**	**compact**	**wet**	**tall grass**	**North aspect**	**South aspect**
Crop trees							
Norway spruce	poor	good	good	good	poor	fair	fair
white pine	poor	poor	poor	poor	poor	fair	fair
Virginia pine	fair	poor	good	poor	poor	fair	good
red oak	fair	fair	poor	poor	fair	fair	good
white oak	fair	fair	poor	poor	fair	fair	good
white ash	fair	fair	good	poor	fair	fair	fair
green ash	fair	fair	good	good	good	fair	fair
yellow-poplar	poor	fair	poor	poor	fair	good	fair
red maple	fair	fair	fair	fair	fair	fair	fair
sugar maple	poor	poor	poor	poor	good	good	fair
sycamore	fair	good	fair	good	good	fair	fair
Nurse trees							
black locust	fair	fair	good	poor	good	fair	fair
black alder	good	fair	good	good	good	fair	fair
bristly locust	good	fair	good	fair	fair	fair	fair
autumn olive	fair	fair	good	fair	good	fair	fair

A designation of "good" does not mean the species prefers the condition, but it is relatively more tolerant that the other species in the list. For example, white ash does not prefer compacted soils, but experience has shown that it will survive and grow better than the other crop trees listed.

CONCLUSIONS

Many coal mined sites in the southern Appalachians were forested before mining and will ultimately be reforested. This will happen either as the result of carefully designed and executed reclamation or by default through natural succession of abandoned hayland/pasture. 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 economic opportunities to the landowner, and they provide society with benefits from the many non-commodity amenities of healthy forests; slope stability, erosion control, watershed protection, wildlife habitat, diversity, esthetics, etc.

SMCRA requires that land be reclaimed to support a post-mining land use that is equivalent to, or "better" than the use before mining. When forestry is the post-mining land use, land should be reclaimed differently and it should look different when finished than hayland/pasture. Restoration of productive forest land requires the construction of a deep, non-compacted, non-toxic minesoil, and the absence of a competitive ground cover. This can be accomplished by (1) selecting oxidized (brown) sandstone for placement at the surface as a topsoil substitute, (2) preventing compaction on level and gently sloping surfaces, (3) using a tree-compatible ground cover to enhance tree seedling survival and early growth, and (4) properly planting a useful mix of tree species on appropriate microsites.

In many parts of the Virginia, West Virginia, and Kentucky coalfields, 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 a healthy forest environment.

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