Session 3

STATUS OF REFORESTATION TECHNOLOGY

Chairperson:
Paul Rothman
Kentucky Department for Surface Mining Reclamation and Enforcement
Lexington, Kentucky

Status of Reforestation Technology: The Appalachian Region
Dr. James A. Burger and John L. Torbert, Virginia Polytechnic Institute and State University, Blacksburg, Virginia

Status of Reforestation Technology and Science in Southern Illinois
Dr. Clark Ashby, (Retired) Southern Illinois University, Carbondale, Illinois

Low Mine Soil Compaction Research
Don Graves, University of Kentucky, Lexington, Kentucky

Use of Field Compaction Measurement to Predict Reforestation Success
Dr. Richard Sweigard, University of Kentucky, Lexington, Kentucky

STATUS OF REFORESTATION TECHNOLOGY: THE APPALACHIAN REGION

James A. Burger[1] and John L. Torbert[2]
Virginia Polytechnic Institute and State University
Blacksburg, Virginia

Introduction: The Opportunity

Reclaimed Appalachian surface mines can be an excellent place to grow trees. Mine soils are often deeper, more fertile, and more productive than natural soils. Landowners or foresters managing mined land also have the opportunity to change the species composition of the forest. Native forests are often dominated by poorly formed trees and unmerchantable species resulting from past mismanagement. After mining and reclamation, these forests can be replaced with fully stocked stands of whatever species landowners choose. For the most part, it is possible to establish any of the common native tree species if the land is properly reclaimed. Pines, oaks, yellow-poplar, and ash have all grown well under the right circumstances. Finally, through the process of mining and reclamation, landowners have the opportunity to have good roads constructed to provide permanent access to their new forests, greatly reducing future management and harvesting costs. These combined factors make forestry a tremendous long-term financial opportunity for owners of mined land. However, proper reclamation and reforestation techniques must be used to ensure that this opportunity is realized.

Research by reclamation forestry groups throughout the Appalachian and midwestern coalfields has shown that productive mine soils and forests can be restored using a "forestry reclamation approach," which basically entails: (1) cooperation among the coal operator, landowner, and regulatory authority in developing the mining permit that details and describes reclamation procedures specifically for forestry land use; (2) replacing desirable topsoil or mixing any recoverable soil with slightly acid, brown, weathered sandstone overburden and applying it a minimum of 4 feet deep; (3) loosely grading noncompacted topsoil or topsoil substitutes that include, when possible, woody debris and native seed pools; (4) using native and noncompetitive domestic ground covers that quickly protect the site from erosion, encourage forest meso- and macro-fauna, and serve a noncompetitive, facilitative role in plant, animal, and forest succession; and (5) planting a proper silvicultural mix of crop trees for their commercial value along with nurse trees for wildlife and soil improvement.

The details of this reclamation approach are described by Burger and Torbert (1992) in a Virginia Tech Extension bulletin (460-123) called *Restoring Forests on Surface-Mined Land*. This forestry reclamation approach has been approved, used, and proven successful, and is the status of reforestation technology in the Appalachian region. However, the process of planting and successfully establishing trees has not been accomplished in many cases due to a lack of understanding of these steps, a resistance toward changing established techniques, and a lack of careful preplanning, supervision, and follow-through. This paper describes a process that helps overcome the constraints, and one that leads to successful reforestation in the Appalachian region.

Reforestation Objectives

Reforestation must serve the combined goals of the landowner and coal operator while meeting standards set forth in regulations derived from the Surface Mining Control and Reclamation Act of 1977 (SMCRA). Therefore, the purpose for tree planting is to establish a community of tree species that will: (1) provide enough ground cover and tree stems of a certain height to achieve bond release for the operator; (2) provide trees of commercial value that will produce timber and other forest values for the landowner; and, to a degree, (3) mimic the natural forest ecosystem with respect to plant diversity, species distribution, aesthetics, and wildlife benefits as required by some regulations in some states. Therefore, there are some aspects of tree planting that are unique to mine soils; however, we believe tree planting, and the forestry opportunities that follow, can be successful and profitable by adhering to a few legal, management, and biological procedures, and by following several steps that are described in the following sections. The objective of this paper is to present the step-by-step guide that has led to successful establishment of trees for future forests in the Appalachian coal region.

Reforestation Technology

Step 1: Landowner (forester), coal operator, regulator coordination prior to, during, and after mining.

Reclamation is a complex process involving landowners, coal operators, and regulators (Figure 1). At the end of the process, the reclaimed mined landscape, its use, productivity, and long-term value, will be determined by the mine operator as he interacts with the landowner and the regulatory authority and follows the requirements of reclamation law. The Office of Surface Mining Reclamation and Enforcement's (OSM) performance standards for mined land reclamation are contained in the Code of Federal Regulations Title 30, Chapter III. One of the objectives is striking a balance between the goals of protecting both the environment and land productivity and the nation's need for coal as an essential source of energy. These goals are basically mutually exclusive; therefore, reclamation success hinges on preplanning and cooperation among the regulatory authority, landowner, and coal operator. The landowner can and should have input into the reclamation process through the development of the mining permit, and the state regulatory authority will ensure that the plan is completed as spelled out in the permit and according to current regulations and guidelines that have been approved by the U.S. Office of Surface Mining.

A landowner who wants to manage reclaimed land for productive forests must make sure the mining permit allows the mine operator to create proper conditions for reforestation. The mining permit application may consist of hundreds of pages, but only a few are related to revegetation. These pages are a very important part of the permit, and their content will determine the future land use, its productivity, and its value.

Reclamation bond monies cannot be returned to the mine operator until reclamation is approved by the reclamation inspector. The 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 specific for reforestation. A mining permit application should include sections on premining land use, postmining land use, topsoiling, surface grading, ground covers, and tree planting specifications.

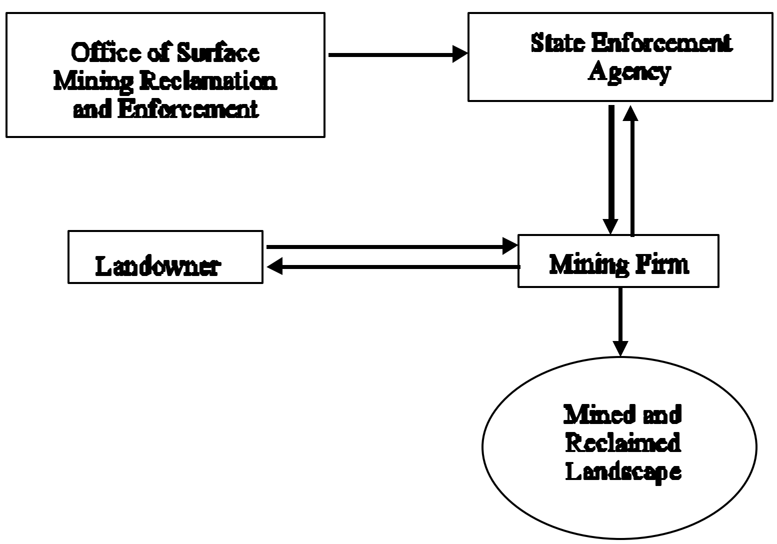

Figure 1. Interactions of the parties and agencies involved in the land reclamation outcome.

The permit should explicitly specify that the premining land use was managed forest. The SMCRA mandates that land be returned to its premining land use or a higher-value use. Therefore, land should not be converted to uses of lesser value such as hayland/pasture or wildlife habitat that will not be actively managed after bond release. Most surface-mined forest land is owned by private and corporate landowners who have long-term economic interests in their forests. Furthermore, in some states, land is taxed at a lower rate if it is managed for forestry. For private or corporate landowners with active or passive timber management programs, land obviously has a premining land use of managed forest.

The permit should also explicitly specify that the *post*mining land use be forestry. The advantages of forestry versus unmanaged land are outlined in Virginia Tech Extension Bulletin No. 460-136 by Torbert et al. (1994) called *Commercial Forestry as a Postmining Land Use*. The coal operator can benefit from reduced grading costs, and the landowner benefits from receiving reclaimed land capable of growing desired tree species at rates that will be profitable. These benefits are seldom realized unless the permit specifies commercial forestry or managed forest as the postmining land use.

The permit can be made specific in order to achieve certain commercial forestry objectives. For example, the permit could specify that the land be used to produce hardwood sawtimber and provide wildlife benefits. The objective could be the creation of a mine soil with a hardwood site index (SI_{50}) of 65 feet or more, which is the average productivity of forest land in the Appalachians. Landowners should confer with the regulatory agency to find out if a forest management plan is necessary, and if so, what is required. It will usually require some estimate of the number of years until harvest and an estimated harvest yield. Forest management plans are simple, easy to write, and help, if needed, can be gotten from a state extension or consulting forester.

Step 2: Topsoil or a suitable substitute selected for trees must be placed, uncompacted, 4 feet thick on the surface of properly reclaimed spoil.

Permits should specify the makeup and final preparation of the site to ensure that reclamation is compatible with a productive forestry land use. Probably the *most* important factor affecting tree survival, growth, and productivity is the quality of the mine soil placed on the surface. Specify that the best available growth medium on the permit area be placed on the surface to an average depth of 4 feet. The growth media should consist of soils or soil substitutes that have low to moderate levels of soluble salts, an equilibrium pH of 5.0 to 7.0, low pyritic sulfur content, and a sandy loam texture conducive to good internal drainage.

The SMCRA requires that topsoil be replaced after mining; however, a waiver of this requirement can be obtained if topsoil is of insufficient quantity or quality for sustaining vegetation. If the topsoil is less than 6 inches thick, the operator may remove the topsoil and unconsolidated materials below it and treat the mixture as topsoil. Selected overburden materials may be substituted for, or used as a supplement to topsoil if the operator demonstrates that the resulting soil medium is equal to or more suitable for sustaining vegetation than the existing topsoil.

Topsoil substitutes are commonly used throughout the Appalachian region, but they are most often selected and justified based on their ability to temporarily sustain the growth of temporary ground covers. These ground covers are made up of introduced species of grasses such as tall fescue that require annual fertilization to remain productive. Most soil substitutes are alkaline, salty, finely textured siltstone materials that are easily compacted and are poorly drained and aerated. They are usually found deep in the profile adjacent to coal seams, and operators find it expedient to place these materials on the surface. However, our research shows definitively that soil substitutes adequate for exotic grasses such as tall fescue are not suitable for native trees.

Figure 2 shows the productivity of trees and grass growing on a gradient of soil substitutes consisting of sandstone media, mixtures of sandstone and siltstone media, and pure siltstone media. Tall fescue grows equally well across these overburden types when its fertility level is maintained by fertilizing. Tree productivity, on the other hand, was adversely affected by the presence of siltstone media. The figure shows a precipitous drop in productivity as siltstone is added to sandstone-derived mine soils. Table 1 contrasts selected chemical and physical properties of these growth media. The sandstone-derived medium had fewer coarse fragments, higher sand content, better water

retention, pH levels similar to native forest soils, and lower total salt levels as shown by electrical conductivity of the soil solution.

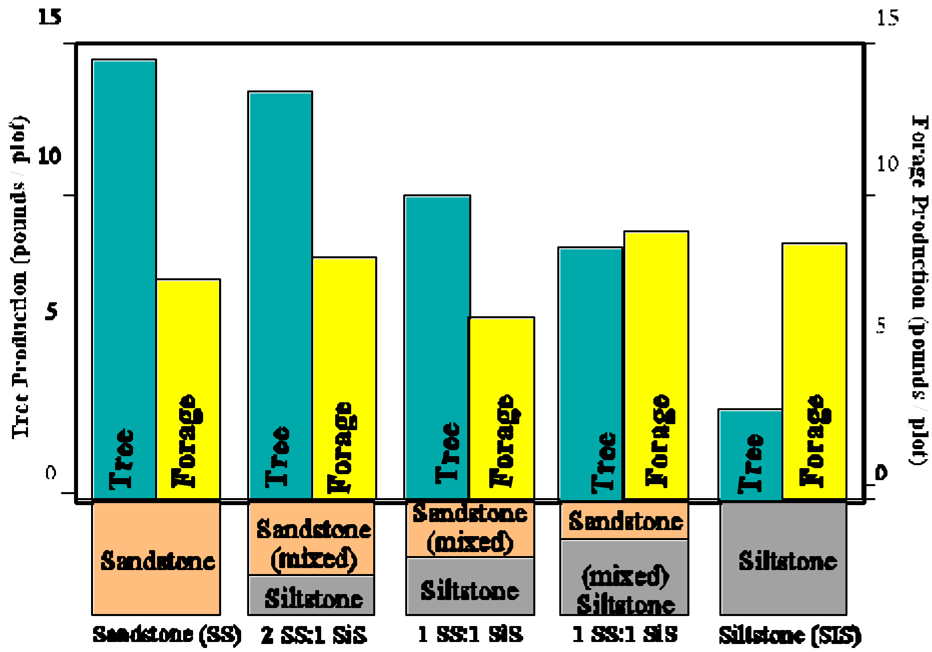

Figure 2. Topsoil substitute effects on tree and forage production (Torbert *et al*. 1990).

This research and years of practical experience show that the best growth medium for trees in the Appalachians is a mixture of the surface soil layers and consolidated but heavily weathered sandstone bedrock beneath the soil surface. The sandstone near the surface is physically and chemically weathered tens of feet deep and quickly breaks up with time to form a high-quality forest soil when mixed with topsoil materials and placed on the surface. Therefore, we recommend this soil substitute for the following reasons: (1) the law requires that appropriate productive topsoil substitutes be used when a topsoiling waiver is obtained; (2) trees and forests will be the permanent vegetation on 95 percent of the mined land, regardless of claimed postmining land uses; abandoned grassland and wildlife habitat become forests via natural succession; (3) due to the profound effect of overburden type on tree growth, weathered sandstone materials near the surface of most Appalachian sites should be used as a

Table 1. Selected chemical physical properties of mine soil (0-20 cm) as affected by mixture of overburden spoil (Torbert et al. 1990).

Rock Mix Treatment	pH	Electrical Conductivity	Exchangeable Nutrients				Available Mn
			P	K	Ca	Mg	
		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 followed by the same letter are not significantly different (a = 0.1).

topsoil substitute if a mined area is destined for trees either by design or default (natural succession); (4) our work shows that in nearly all cases, any mix of the surface 10 feet of soil and rock makes an excellent growth medium for virtually all native tree and herbaceous species; (5) applying a minimum of 4 feet of this mix of material without compaction creates a topsoil substitute that is usually as productive or more productive than the original soil `ue to its greater depth; (6) woody debris mixed in or laying on the surface creates microsites for native species; and (7) less grading and seeding is needed for forestry land uses, making the use of this topsoil substitute cheaper for the mine operator.

Step 3: Minimize grading and tracking of the surface.

Permits should specify that level areas and gentle slopes be lightly graded to avoid compaction, and that final surface roughness resemble natural forest land. Uncompacted soil is essential to achieve postmining land use of forestry. Minimizing soil compaction during the application of the surface materials and final grading is extremely important.

Compaction can be minimized by dumping and leveling in separate operations. To achieve this on relatively flat areas, the rooting medium should be placed in tightly placed piles that abut one another across the entire area. Once the material is in place, a bulldozer can be used to grade the tops off the piles and gently level the area with one or two passes. For those mining operations that utilize draglines, the soil material can be cast and shaped in a manner that reduces the amount of final grading needed by tracked equipment. The final surface layer of material should first be placed in tightly spaced piles or ridges that abut one another across the entire area and subsequently graded in a gentle fashion with one or two passes using low-ground-pressure equipment. On steeper areas, the suitable growth medium should be dumped over the top of the outslope on the previously compacted backfill. Again, one pass with a bulldozer should be sufficient to minimally shape the slopes.

There are many research reports and demonstrations showing the effects of compaction. The results of a Powell River Project study (Torbert and Burger, 1994), conducted in cooperation with Pocahontas Land Corporation and Martiki Coal Company in eastern Kentucky, clearly show the effects of compaction on tree survival and growth after five years (Table 2). The study was installed on a recently reclaimed area with a 40 percent slope. Typical and traditional site preparation is depicted by the “intensive” grading treatment. “Moderate” grading consisted of complete leveling of the surface with three to four passes of a bulldozer. The “low” grading level, striking the surface with a single pass, originally planned for this study was untested because we were unable to obtain approval for this treatment. The “ripped” treatment consisted of ripped planting rows on typical, intensively graded surfaces created by a standard 2-foot rock ripper pulled by a dozer. The greatly improved survival and growth of the nonstandard, less compacted treatments is striking (Table 2). Based on our other studies and observations, we found that low-level grading produces early results similar to those of the ripping treatment, and low-level grading outperforms heavily graded ripped sites as trees try to use the whole soil volume. Because compaction can be avoided in the first place, we recommend ripping only as a last, expensive resort.

Table 2. Grading intensity effects on soil erosion, ground cover, and tree growth.

Grading Treatment	1st Year Soil Erosion	5th Year Ground Cover	Fifth-Year Tree Survival and Growth							
			Yellow Poplar		Sycamore		Sweetgum		White Pine	
			Survival	Ht.	Survival	Ht.	Survival	Ht.	Survival	Ht.
	(in)	(%)	(%)	(in)	(%)	(in)	(%)	(in)	(%)	(in)
Intensive	0.3	85	3	17	50	32	39	20	0	---
Moderate	0.2	90	38	39	63	43	41	33	7	20
Low* (untested)	?	?	?	?	?	?	?	?	?	?
Ripped	nondetectable	83	69	31	77	56	74	24	2	17

*This planned treatment was not installed because approval could not be obtained.

First-year erosion on the treatment areas, measured with erosion rods, showed increasing amounts of erosion with increasing amounts of grading. Compacted mine soils increase surface runoff and soil movement. Ground cover was equally good across all treatments at 85 to 90 percent cover. Tracking-in slopes is not required to achieve a ground cover suitable for erosion control. The additional compaction caused by tracking-in operations reduces water infiltration and increases runoff and erosion.

The cost of preparing the final surface of mined land is approximately $300, $200, $100, and $400 for the intensive, moderate, low, and ripped treatments, respectively. We estimate that the operator could save $200 to $400 by properly preparing sites for trees, mainly by reducing the amount of grading that is commonly applied to all reclaimed surfaces regardless of the permitted postmining land use.

Regardless of whether the mined area is a mountaintop, dragline, or steep slope operation, minimizing tractor traffic minimizes compaction, which minimizes the negative effect on forest site quality. Natural forest sites and soils have a diverse microtopography with large amounts of organic matter and coarse woody debris. Many natural forest sites are also rocky, yet very productive. The combination of microtopography created by small depressions, hills, gullies, mounds, rocks, and coarse woody debris is more natural and creates a surface more amenable to recruitment, establishment, and survival of diverse, native forest species, both flora and fauna. Therefore, to the extent possible, final grading should be conducted to minimize compaction, create a surface microtopography, leave as much organic debris as possible, and leave occasional rocks, especially when their removal becomes counterproductive due to additional tractor traffic. Erosion rills and gullies should not be filled if the gullies are stable.

Step 4: Use tree-compatible ground covers to achieve necessary erosion control.

The permit should specify that a tree-compatible ground cover (Table 3) will be used to control erosion, facilitate tree establishment, encourage native plant establishment, and develop a diverse plant community that is typical of native forest ecosystems. Reforestation requires a carefully planned balance between ground cover and tree requirements for light, water, and space. Ground cover should include grasses and legume species that are slow-growing, are tolerant of low to moderate soil acidity (pH 4.5 to 6.5), and can be established in a bare mineral spoil.

Table 3. Species and fertilizer recommendations for a tree-compatible ground cover for recommended mine soils in the Appalachians.

Species	Application Rate (lbs/acre)
Grasses:	
Winter Rye (*Secale cereale*) or Wheat (*Triticum aestivum)* (fall seeding)	15
Foxtail Millet (*Setaria italica*) (summer seeding)	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
Ladino or White Clover (*Trifolium repens*)	3
Fertilizer (elemental rate):*	
nitrogen	50-75
phosphorus	80-100

* Blend 200 lbs/acre concentrated super phosphate with 300 lbs/acre 19-19-19 fertilizer, or equivalent.

Tree-compatible ground covers are relatively sparse during the first year and become increasingly lush by the second and third years. This allows tree seedlings to emerge above the ground cover and ensures their survival. The success that occurs with the ground cover mix shown in Table 3 is based on the ecological concept of "initial floristics" that entails full recruitment (planting, sowing, and natural invasion) of all species at the point of disturbance, followed by successive dominance at different times by each vegetation type (Figure 3). For example, the grasses dominate the first two years providing erosion control. The annual cereal grains grow quickly but sparsely, and when they lodge after the first growing season, their stems mulch the surface. The legumes are selected to establish slowly, but provide nearly complete ground cover by the third or fourth year, displacing the grasses and fixing soil nitrogen at a time when fertilizer nitrogen has played out. These legumes are acid-tolerant, persistent until shaded out by a tree canopy, and have a sprawling growth form to prevent overtopping of tree seedlings. Nitrogen fixing nurse trees that benefit wildlife dominate from age five to ten without competing excessively with the crop trees. By age ten to fifteen, the permanent tree species close canopy and dominate the site. Species for all the vegetation types, grasses, legumes, nurse trees, and crop trees, are carefully selected to play a specific facilitative role in this successional process. All planting and seeding is done at the time of disturbance, and the vegetative system will take care of itself as it provides the functions of erosion control, soil building, nitrogen fixation, water infiltration, wildlife food and habitat, carbon sequestration, and forest establishment.

Kentucky-31 fescue, sericia lespedeza, all vetches, clovers (except ladino or white clover), and other aggressive or invasive species should be avoided. To be compatible with trees, a herbaceous seed mixture should contain grasses, legumes, and small grains. A balanced seed mixture will provide short-term and long-term erosion control without inhibiting tree growth or survival. The fertilizer applied with ground covers should have a high rate of phosphorus and a low rate of nitrogen. Blending 200 lbs/acre of concentrated super phosphate with 300 lbs/acre of a standard 19-19-19 fertilizer will achieve this high phosphorus, low nitrogen, fertilizer mix. The low rate of nitrogen (compared to typical rates used for hayland/pasture mixes) reduces the height of the ground cover but not its density. By the third year, the inoculated legumes will provide an adequate supply of nitrogen.

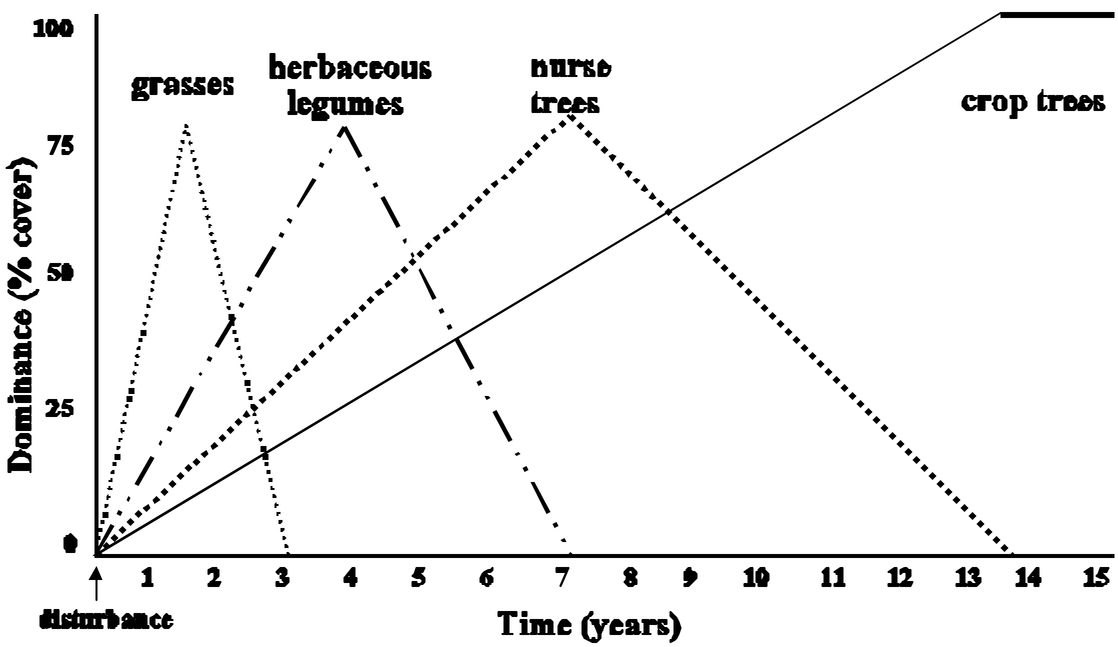

Figure 3. Initial floristics succession: All vegetation types are sown or planted at the point of disturbance, but each type facilitates and yields to another at the appropriate time.

Step 5: Select proper tree species and hire a reputable tree planter.

a. Permits—Mining permits must be written to give the mine operator and tree planter some flexibility with regard to which species to plant where. In the past, problems have occurred because permits were too narrowly worded. For example, if a permit specifically listed only four species to be planted, then those four trees had to be planted. If the list specified white pine, black locust, autumn olive, and bicolor lespedeza, they all had to be there for bond release. If for some reason the operator substituted virginia pine for white pine, the inspector could require the operator to either replant with white pine or change the permit. Both are expensive. Bond release can be, 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 reclamation inspector does not have the authority to change a permit. This is done by another part of the regulatory agency.

The following paragraph is an example of language that provides needed flexibility while ensuring proper reforestation and compliance with the law:

> *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, or other native trees designated by the landowner. At any given location, the specific species selection will be based on good silvicultural composition, seedling availability, and 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. In addition to those planted, some of these species may be established by direct seeding, and some invasion of native species is expected.*

b. How Many Trees to Plant**S**In most states, bond release requires 400 stems per acre. To guarantee bond release, approximately 600 stems per acre is a good planting density. Approximately 200 per acre can be expected from sowing nurse tree seed and from natural invasion if a tree-compatible cover is used on a suitable soil. If pines are selected as the crop tree, about 400 per acre should be planted. If hardwoods are planted, 200 to 300 trees per acre comprised of several species should be planted. However, certain species mixes can and should be specified in the permit to meet landowner objectives. With planting, seeding, and natural invasion, this should provide enough stems for bond release. With the pines or hardwoods, another 100 nurse trees per acre should be planted, in addition to the seed sown, to guarantee stocking and to provide some diversity and wildlife benefits.

c. Direct Seeding Trees**S**Direct seeding can be an important part of the reforestation strategy because it provides the opportunity to establish nurse tree species at very little cost. This cost savings can offset the increased cost of planting some of the crop trees. Black locust is the most reliable species to hydroseed. Historically, the use of black locust has been abused by sowing excessive rates that produced thousands of trees per acre. If black locust is desired as part of a mix of tree species, no more than 200 trees per acre should be allowed in the stand. If the recommended tree-compatible ground cover is used, one-half ounce of locust seed per acre with the ground cover seed mix should provide the right number of established seedlings. Autumn olive and bicolor lespedeza can also be established by direct seeding; however, we do not have enough experience to make a seedling rate recommendation. Operators can start by applying one ounce per acre and increase or decrease rates based on experience.

d. When to Plant**S**Regulations require trees to have been planted for at least two years before final inspection. Sometimes it is advantageous to delay planting until two years before bond release. 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. Furthermore, in the event that aggressive ground covers containing Kentucky-31 fescue and red clover were planted, they will usually become less aggressive with time; after three years the clover may be gone, thereby increasing tree survival. On the other hand, if a tree-compatible ground cover is used, trees should be planted as soon as possible because the ground cover becomes more aggressive with time.

If mine soils were improperly selected and prepared, decide as soon as possible what to plant based on soil/site conditions. For example, if it is obvious that a lot of compacted, gray mine soil is present, don't plan to use white pine. Instead, choose several appropriate species and place an order with a good nursery as soon as possible. Try to arrange a firm pickup date, and be sure a reliable tree planting crew will be available when trees need to be planted (December to March).

e. What to Plant—Most pine and hardwood species that are native to the region should grow well, provided all of the appropriate mine soil conditions exist. To achieve the multiple objectives of erosion control, bond release, nitrogen fixation, wildlife benefit, and native trees that will eventually have commercial value, a mixture of "nurse" trees and "crop" trees is recommended. Nurse trees and shrubs like bristly locust, bicolor lespedeza, autumn olive, and black alder help meet several reforestation objectives, but will eventually yield to the crop tree species that will dominate the canopy in the future. Crop trees on moist to wet sites could include red oak, green ash, yellow poplar, and sugar maple. On drier sites, a mix of white oak, chestnut oak, black oak, white ash, and red maple is recommended. Pure stands of white pine will be successful on moist sites. For the driest, harshest sites on steep south and west aspects, pitch x loblolly pine hybrids and virginia pine will be most successful.

In some cases, the landowner might be interested in growing a specialty forest crop such as Christmas trees or royal paulownia. These tree crops can be successfully produced on mine soils. Several Virginia Tech Extension publications listed in the reference section describe the procedures for establishing these crops (Torbert *et al*. 1989; Torbert and Johnson 1990).

f. Matching Species and Site Types**S**The best mine soils for tree establishment and growth have a sandy loam texture, are loose, uncompacted and well drained, and have slightly acid pH levels. In many cases, these conditions don't exist, and tree species specifically suited to the mine soil and site conditions must be planted to ensure reforestation success. There are several soil/site conditions that influence tree survival and growth and the selection of certain species. These conditions are (i) spoil type, (ii) degree of compaction, (iii) herbaceous vegetation, (iv) wetness, and (v) slope aspect. Table 4 contains a species/site matrix that provides a tolerance rating of various species for different mine soil 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 nontolerance, 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 than the other species on the list. For example, white ash (*Fraxinus americana*) does not prefer compacted soils, but experience has shown that it will survive, and its growth does not seem to be as badly affected as the other crop trees listed (Zeleznik et al. 1993).

Soil pH seems to influence a suite of chemical properties that determine plant growth (nutrients, soluble salt concentrations, P-fixing capacity, etc.). A pH range of 4.5 to 6.5 is suitable for most tree species and typical of natural soils. In the southern Appalachians, the weathered, brown-colored spoils, especially sandstone, fall within this range. The natural occurrence of plant species such as broomsedge, coltsfoot, and lespedeza often indicate mine soil 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 can often be identified 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. High-pH spoils are common in the southern Appalachians. Spoils with a pH of 7.0 to 8.0, usually siltstones or calcareous sandstones, are often encountered. Their presence seems to be indicated by a scarcity of any native volunteer vegetation on bare spoil. High-pH sandstones

Table 4. Species tolerance ratings for various adverse mine soil conditions.

	Mine soil Condition*

Species	pH <4.5	pH <6.5	Compacted	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
Pitch/Loblolly hybd	fair	poor	fair	poor	fair	good	good
Red Oak	fair	fair	poor	poor	fair	fair	good
White Oak	fair	fair	poor	poor	fair	fair	good
White Ash	fair	good	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 that it is relatively more tolerant than other species on the list.

seem to decrease in pH more rapidly than siltstone. Within a few years, high-pH sandstone may become tolerable to some hardwood species. A plant that seems to indicate that pH has decreased to an acceptable level is coltsfoot, which flowers early in the spring with a flower that looks very similar to dandelion. These different spoil pH types influence seedling survival and growth. Each tree species has a preferred pH range within which it has a reasonable likelihood of survival. Virtually all native species are tolerant of moderate acidity. 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 pH less than 3.5 or greater than 8.0.

Compaction results from surface grading and other equipment traffic. Compaction is most severe on level areas and on the shoulders of slopes where bulldozers pivot and turn to start another pass down the slope. Compaction also tends to be more severe on siltstone-derived mine soils than sandstone-derived mine soils. Soil compaction results in less rooting volume, higher soil strength, and less available water. 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.

Poor drainage is usually due to mine soil compaction. Compacted flat areas cause water to stand on the surface for extended periods after a rain event. Norway spruce, green ash (*Fraxinus pennsylvanica*), swamp white oak, sycamore, and black alder are tolerant of wet sites.

Slope aspect is a relatively minor consideration on many sites, but it is most important on steep slopes. Mine soils on north-facing slopes will be cooler and moister than southern aspects. Therefore, species that are less tolerant of droughty soils, such as sugar maple (*Acer saccharum*), should be planted on north slopes. Species such as virginia pine and chestnut oak are more tolerant of southern aspects.

g. Dealing with Herbaceous Vegetation—When a traditional reclamation seed mixture consisting of aggressive grasses and legumes 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 is most aggressive on near-neutral to high-pH mine soils. As already mentioned, these are the spoils that are not very conducive to tree growth and, therefore, the trees are already somewhat stressed by the unfavorable mine soil chemistry. The cumulative effects of undesirable spoil type and excessive competition can be lethal.

Some species are better suited for dense ground covers because the seedlings are taller than the grass. It's possible to get many hardwood seedlings that are 50 to 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.

h. Seedling Handling and Planting Techniques**S**Many attempts to establish trees have failed because of poor planting techniques or mishandling of seedlings before planting. Most coal operators rely on tree planting contractors for planting. Many contractors working on mined land 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 mine soil or in thick grass. The most important conditions for successful planting are: (1) starting with healthy seedlings; (2) taking care of them (keeping them refrigerated) until they are properly planted; (3) matching species to site; and (4) supervising the planting operation.

Coal operators planting large quantities of seedlings should make arrangements with nurseries well in advance to be sure of an ample supply. When seedlings are in short supply, the operator may have to settle for inferior seedlings that may be smaller (or larger) than desired, they may have to come from a distant nursery, and they may not be the best species for the site. Good quality planting stock is essential for good survival and early growth. Seedlings should be large enough to have a healthy root system, but not so large that it is not possible to properly plant the seedlings.

Seedlings should be picked up from the nursery just before planting begins, and, ideally, the seedlings should be lifted from the nursery bed immediately before pickup. Seedlings must be stored in a cool, moist, and aerated environment. A refrigerated truck or storage area kept at 40ºF is ideal.

There is a tendency for some tree planters to excessively prune roots, and some have been known to top-prune shoots of hardwoods below the point of live buds on the stem. Some planters have pruned seedlings to the point where death is almost certain. Pine seedlings should not be top-pruned at all, and hardwoods should not be pruned below the point of live buds. Roots should never be pruned. During planting, roots must be protected from drying, and they should never be exposed to the sun or wind for more than a few minutes. Water-absorbing gels can be used as a root dip or spray to help prevent drying in the field before planting. 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 a single species, but adjoining rows are different species. Better seedling survival and growth and a better silvicultural mixture of species would result if contractors had each planter carry three or more species, and each planter made an effort to put the right species on the right site with regard to aspect, slope, degree of compaction, soil wetness, and ground cover competition (Table 4).

Proper microsite selection requires a good understanding of mine soil properties affecting tree growth, and some understanding of different species' site preferences. This may not be practical for all tree planting operations, but with proper supervision and training this can be accomplished for planting reclaimed mine sites. For example, if planters were carrying red oak with large roots, white pine, autumn olive, and black alder, they could plant the oak whenever an excellent planting hole in loose 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 also seems to be relatively tolerant of compaction and could be planted on average to harsh sites.

Site selection should also be based on slope position and aspect. For example, red oak, green ash, sycamore, and black alder should be planted at the toes of slopes where it is likely to be wetter. White ash and white oak should be planted further up the slope on drier positions. 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.

i. Supervision**S**A lack of supervision of tree planters and some planting contractors is clearly an important reason for many of the tree planting failures that have occurred on mine soils. Planting contractors paid on a per-seedling basis often lack the incentive to carefully plant each seedling or to plant seedlings on a desired spacing. It is common to see seedlings planted on a very wide spacing on poor soils where it is difficult to make a good planting hole, and to see trees planted less than a meter apart from each other on uncompacted mine soils where it is easy to plant trees. A representative of the landowner or coal operator knowledgeable in tree planting 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" or "hoedads." Hoedads are faster and are commonly used for planting on sandy soils in the southern U.S. Conscientious planters can successfully plant trees in mine soils with hoedads if mine soils are uncompacted.

Applying Reforestation Technology

In the past three years, regulatory agencies of three Appalachian states, Virginia, Kentucky, and West Virginia, have developed new guidelines and procedures for reclaiming mined land permitted for a postmining land use of forestry or forest land. These new guidelines and procedures are largely based on the research results conducted by the Powell River Project throughout the Appalachian coalfields.

In July 1996, the Virginia Department of Mines and Minerals and Energy, Division of Mined Land Reclamation, issued Memorandum 3-96 to coal operators, consultants, and DMLR personnel that described *guidelines for husbandry and reclamation practices appropriate for forestry postmining land uses*. Four reclamation practices including spoil selection, grading, tree-compatible ground covers, and tree species selection are described that are based on the steps for reforestation outlined above. Since 1997, more than 85 percent of new permits were written with forestry as the postmining land use. This represents a complete reversal given that only about 15 percent specified forestry in 1987.

In March, 1997, the Kentucky Department for Surface Mining Reclamation and Enforcement issued a Reclamation Advisory Memorandum 124 describing the rationale for new reclamation guidelines and the new reclamation practices that would accomplish reforestation goals. These guidelines were more detailed than those in Virginia's memorandum, but they covered the same practices and essentially made the same recommendations.

The Kentucky reforestation initiative was prompted by a resolution sent to the governor of Kentucky from the Kentucky Environmental Quality Commission called a *common sense initiative to enhance tree planting as a viable reclamation option to promote more productive postmining land uses while minimizing reclamation costs*. It resolved that a work group (1) review current practices that inhibit tree planting and develop other options, allowable under PL 95-87, to promote forestry land uses; (2) conduct training programs for field inspectors and permit writers; (3) develop a technical assistance program and demonstration projects to better inform landowners about the multiple values of forest land; (4) promote tree planting on abandoned mined land; (5) convene a task force to assess postmining land uses and reclamation practices and report findings to the secretary of the Natural Resources and Environmental Protection Cabinet; (6) recognize the important role that research plays in improving reclamation practices; and (7) support efforts to phase out non-native and invasive species and provide greater diversity of native tree species.

This resolution provided the foundation to change the troublesome 20-year mindset within the reclamation community that caused the use of intensive grading to create mostly unwanted grasslands, consisting of exotic, invasive species, in the name of erosion control.

The actions that followed, in particular RAM 124, provided the authority and technical guidelines to accomplish the goals of the reforestation initiative. This process, developed and used in Kentucky, is a good model for other states to emulate.

A third and most recent initiative in West Virginia also encourages reforestation of mined land. In June, 1998, a memorandum of understanding between the Division of Forestry and the Division of Environmental Protection, Office of Mining and Reclamation, was signed. It recognizes "*the desirability of a healthy forestry industry in the state,*" and the need to "*provide assistance to those mining companies and landowners who wish to develop commercial woodland as the postmining land use on their properties.*" It provides for reduced stocking rates, but requires that the permittee have an approved management plan prepared by a registered professional forester. Detailed procedures have been outlined for developing the permit which are easy to follow and accomplish. Reclamation guidelines for preparing mined sites for reforestation are also included. They are similar to those used by Virginia and Kentucky and are also based on Powell River Project research. An important difference is the requirement for a professional forester to review the plan. This is desirable and will help ensure the success of the reforestation plan.

The development of these reforestation initiatives by regulatory personnel in these three states is commendable and an encouraging development. It shows that new techniques, underpinned by sound research and common sense, can be incorporated in reclamation procedure for the benefit of all involved. Furthermore, this conference pro-ceedings is an encouraging development; it is an example of the positive and proactive role that OSM can play to advocate and enhance better reclamation and postmining productivity and land use while ensuring energy pro-duction for the nation's needs.

Conclusion

Establishing productive forests on reclaimed mined land is both possible and profitable, but this land use opportunity must be properly planned, managed, and coordinated. This report encourages cooperation between the landowner, coal operator, and regulator in the mining permitting process; outlines the proper reclamation techniques specific to forestry; and recommends the hiring of foresters and tree planting crews that understand the special conditions and requirements for reforesting reclaimed mined land. The combination of these activities will ensure that the mine operator will achieve timely, cost-effective bond release, and that the landowner will achieve a productive use of his or her land. Other reports referenced below provide more detail of the land reclamation process needed to achieve productive forests.

References

Burger, J. A., D. L. Kelting, and C. Zipper. 1998. Maximizing the value of forests on reclaimed mined land. Virginia Cooperative Extension Pub. 460-138.

Burger, J. A., and J. L. Torbert. 1992. Restoring forests on surface-mined land. Virginia Cooperative Extension Pub. 460-123.

Torbert, J. L., J. A. Burger, and J. E. Johnson. 1994. Commercial forestry as a postmining land use. Virginia Cooperative Extension Pub. 460-136.

Torbert, J. L., J. A. Burger, T. J. Nichols, and J. E. Johnson. 1989. Growing Christmas trees on reclaimed surface-mined land. Virginia Cooperative Extension Pub. 460-116.

Torbert, J. L., and J. E. Johnson. Guidelines for establishing *Paulownia tomentosa* on reclaimed mine soils. Virginia

Cooperative Extension Pub. 460-118.

Torbert, J. L., J. A. Burger, and W. L. Daniels. 1990. Pine growth variation associated with overburden rock type on a reclaimed surface mine in Virginia. *J. Environ. Qual*. 19:88-92.

Torbert, J. L., and J. A. Burger. 1994. Influence of grading intensity on ground cover establishment, erosion, and tree establishment on steep slopes. p. 226-231. In: Vol. 3, Proc. International Land Reclamation and Mine Draining Conference. U.S. Dept. of Interior Bureau of Mines Special Publ. SP 06C-94.

---

[1]Dr. James A. Burger is Professor of Forestry and Soil Science, College of Forestry and Wildlife Resources, Virginia Polytechnic Institute and State University.

[2]Dr. John L. Torbert, formerly a Research Associate at Virginia Tech, is Research Forester for Mead Coated Board Corp., Phenix, Alabama.

STATUS OF REFORESTATION TECHNOLOGY IN SOUTHERN ILLINOIS

W. Clark Ashby[1]
Department of Plant Biology, Southern Illinois University at Carbondale
Carbondale, Illinois

Abstract

Reforestation can be successful when seed or seedlings of desired tree species are planted in a suitable rooting medium. The technology of tree planting is well-developed and has been presented in various manuals and handbooks. This technology has not led to successful reforestation post-SMCRA due to several reasons, primarily the widespread absence of a suitable rooting medium. The widely replaced fine-textured prime farmland with fragipan and claypan subsoils in southern Illinois is inherently massive with deficient aeration and deficient water entry and drainage essential for root growth. The separated and replaced surface unconsolidated materials are readily compacted and further limit soil aeration and water movement. When dry, they have excessive soil strength that precludes adequate root growth. Tree roots and tree seedlings on these restored pan soils die during seasonal stress periods from saturated or from dry soils.

Potential forest biomass accumulation is further limited by planting competitive ground cover to control the erosion resulting from excessive water runoff on lands with replaced impermeable soils. The adverse effects of ground cover are exacerbated by resulting excessive animal populations that eliminate portions or all of annual tree plantings.

These causes of failure in forestation would be minimized if a suitable rooting medium were available for fast-growing trees using available tree planting technology. The cast overburden after mining is naturally rich and productive with desirable water relations. If mixing the mineral riches of coarse fragments from lower in the overburden with top-dress material were permitted, reforestation problems would greatly be lessened. Forestry is a longer-term, higher, and better land use than restored marginally productive corn fields that likely will be abandoned. With no diagnostic criteria for prelaw forest land, have the permitted acreages designated as forest in the lower midwest been adequately reported, or have forest lands been converted to other uses? Forestry is a logical and necessary beneficial land use that should be implemented on a greatly increased scale for mined lands in the lower midwest.

Introduction

The vast coal reserves of Illinois are overlain by strata of nutrient-rich limestones, sandstones, and/or shales; by unconsolidated weathered rocks, glacial drift, and/or loess; and by varied types of soils with regionally distinctive soil horizons and with equally distinctive presettlement vegetation types. Northern and central Illinois lands that were "strip-mined" by the Wisconsin glacier in relatively recent geologic time have fresh, mineral-rich, highly productive soils developed under prairie. Southern Illinois has ancient, weathered, relatively unproductive soils developed under forests.

Standard practices for mining the underlying coal may be applicable for northern, central, and southern Illinois. Attempting to apply standard reclamation practices to replace the overburden in the diverse ecosystems is, however, counterproductive and ecologically irresponsible. Different reclamation/revegetation practices are needed for the forest soil types and climates of southern vs. the prairie region of central/northern Illinois.

A chief visual distinguishing feature of forests as ecosystems is high biomass values, resulting from large-scale, long-term carbon sequestering. The underlying necessary high rates of photosynthesis depend on a capacious underground root system, and an ample aerial canopy of trunks and branches. An unsuitable rooting medium limits or eliminates successful tree growth. The potential for reforestation success or failure is largely determined before a tree seedling is put in the ground.

Reforestation from the 1930s to the 1960s, when state laws in Illinois began to affect lands surface mined for coal, was overall highly successful on mixed overburden minesoils, also called spoil (Ashby 1996A). Those ecosystems today have sustainability, resistance to invasion, nutrient retention, high water quality, and productive biotic interactions. Planting conditions and success greatly changed with the implementation of P.L. 95-87, The Surface Mining Control and Reclamation Act of 1977 (SMCRA 1977), with its emphasis on restoration (preservation) of pre-mining soils, especially "prime farmland." "Prime farmland" and "topsoil" seem to be elusive or elastic concepts and are not defined in the Illinois Act (Illinois Mines and Minerals [IDMM] 1980). Preservation is not necessarily, or even commonly, the most responsible stewardship of natural resources. Government does tend to resist new ideas. New people tend to make the old mistakes.

In 1982, IDMM promulgated a "prime farmland fragipan soil" rule #1823.14 to include the Ava, Grantsburg, and Hosmer soil series in contradiction to extensive published soils data. Grossman *et al*. (1967) noted that biequal soils with fragipans are common in southern Illinois. Fragipans are examples of massive structure (Kohnke 1968). Much acreage restored with fine-textured, massive, acidic, and infertile prime farmland soils does not have potential long-term productivity. Because corn and other crops must be grown to "prove" productivity for bond release, trees are outlawed (IDMM 1993).

Actually corn production today is a highly intensive gamble, with an army of specialists to take care of everything on nonflooded soils except the weather. A lucky high-yield year proves little. An appropriate test for long-term productivity would be to plant tuliptree or black walnut. Crops could simultaneously be tested using agroforestry practices developed by Dr. Gene Garrett at the University of Missouri.

Trees are a product of the soil. High quality hardwoods such as black walnut and tuliptree (yellow poplar) that need good soil drainage have not successfully been grown on the post-SMCRA restored soils to my knowledge. Species able to tolerate seasonally perched water tables with limited aeration and excessively high soil strength in the dry season are needed. Tree species planted to get adequate survival for bond release on the restored soils now commonly come from bottomland habitats.

My use of the term "topsoil" simply means top-dress material (USDA 1951). The typical premining worn-out, eroded, abandoned fields in southern Illinois commonly have little or no A_1 topsoil remaining to put back, and inferior, unproductive A_2- and B-horizons are replaced as top-dressing material or top dirt.

This paper evaluates why tree planting is a limited postmining land use in southern Illinois. The factors tending to advance or to constrain reforestation acreage and success are grouped and evaluated under four categories (Table 1).

External Technological Factors
Tending to Constrain Reforestation Acreage and Success

1. **Minor status of forestry as one of the authorized and appropriate postmining land uses.** Postmining land uses specifically mentioned in SMCRA and in the Illinois Act include intensive agriculture, fish, and wildlife. There are a dozen places in the Illinois regulations where crops or fish or wildlife are specified, and not forestry. Despite studies showing greater long-term economic returns and ecological benefits on appropriate sites from forests than crops, forestry invariably seems not to be accepted as a higher or better land use.

   Neglect or suppression of forestry is evident in other ways. No review of permits by a forestry agency or forest soils person is indicated in the Mines and Minerals annual reports. In contrast, crop production requirements in a permit are reviewed by the USDA Natural Resources Conservation Service (NRCS), the Illinois Department of Agriculture, and a crops soils person.

2. **Lack of criteria for specifying forested acreage.** What is forest, or more importantly, what premining lands should be designated as forested? With the absence of criteria both in the federal and in the state legislation

and regulations, and lack of permit review by foresters or forest soil specialists, chances of proper designation and/or enforcement are unduly limited. How much of the premining acreage now termed "wildlife" should properly be reported as forest? Why is there not a "historically used for forest" as well as the "historically used for cropland" provision in the regulations? Are forested lands that have commonly been harvested or otherwise disturbed before mining no longer called forest? Such lands rapidly regenerate in an ongoing cycle of forest development.

3. **Inadequate designation in permits of premining forested acreage.** Guidelines and standards are needed so that forest cover is properly accounted for at all stages in permitting and reclamation. Was SMCRA intended to be a mechanism for eliminating forestry acreage? Let us look at the record.

   Whether forest acreage is restored after surface mining for coal is determined in part by the permitting process that may or may not provide for tree planting. If trees are planted, there will be a ground cover. If the trees fail or are not planted, a permit modification can accommodate an herbaceous wildlife designation. Of the 14,087 acres permitted to forest from 1983-93, only 30 acres or 0.2% had Phase III bond released by 1994. Perhaps some of the originally designated 14,087 acres had bond released under another land use than forest. I do not have sufficient information to document how much postmining forest acreage may be lost in this way.

   Two recent permit applications in southern Illinois were analyzed for pre- and proposed postmining forest acreage. Both lie within 50 miles west of Evansville, Indiana and are bordered by the Ohio/Wabash River system. A Gallatin County application was for 1500 acres and a White County application for 2402 acres. All forest is to be eliminated in the mined areas of both permits, 90 and 353 acres, respectively (Table 2). These two examples illustrate the superficiality of claims that forest acreages are being replaced. The acreages for unspecified wildlife vegetation increased by 172 and 354 acres, respectively. Areas designated wildlife are reclaimed to diverse land uses such as wetland, herbaceous, shrubland, or woodland. Of the total acreage for these mining permits, 68 percent and 51 percent, respectively, are set aside even if in forest premining by being designated “prime farmland.” If mined, these acres must be returned to row crops regardless of previous land use (IDMM 1993). The U.S. National Erosion Inventory 1977 reported 602,000 Illinois acres of prime farmland in forest. Illinois also has a "high capability" land use category. On any land so labelled, "The total soil profile, including subsoil and topsoil, must be a minimum of 48 inches for prime farmland and high capability land, including fragipan soils" (IDMM 1993). What use really are these lands?

   Tree planting is not forbidden on land designated high capability as it is for prime farmland. Trees are, however, unlikely to be planted on poorly drained, fine-textured, compacted soils with a required highly competitive ground cover and associated dense animal populations that together lead to failure of the plantings.

4. **Lack of regulator support for industry tree-planting operations and company downsizing of reforestation programs.** The pre-SMCRA choice of reclamation to trees on lands surface mined for coal was based on a national consensus in the 1930s and 1940s that endorsed tree planting for conservation purposes. Pine trees were planted by the Civilian Conservation Corps on the worn-out agricultural fields purchased for national forests and by other agencies for shelter belts in the Dust Bowl. Thus in 1977 when SMCRA was passed, the coal industry had an invaluable cadre of dedicated reclamation personnel with years of experience in successful tree planting. These people were given budgets to hire dozens of recent forestry and other graduates and started ambitious tree planting programs. Research money was given to universities in eastern and midwestern coal-mining states.

   A recognition of the values of tree planting vanished in the confrontations of the 1960s and 1970s. When SMCRA was drafted, the forestry community was sidelined and idealistic and ignorant, feed-the-world activists resolved to have soils restored at any price for crop production. Buzz words such as "prime farmland" became almost sacred, and its restoration/preservation the political touchstone to success. Unfortunately, the restoration of worn-out, eroded fields did not, and could not, restore long-term productivity.

   The coal industry soon realized that to achieve successful reforestation required drastic changes in tree planting to accommodate the drastic changes on the post-SMCRA lands. Requests for needed changes based on planting experience and research were ignored and opportunities for experimental practices were unful-filled. The companies gave up the unequal struggle, let most of their reforestation people go, and reassigned some others. Wetland and herbaceous wildlife acreages took over the noncropped lands to a great extent.

Technological Factors Tending to Constrain Reclamation Success

1. **Restoration of an unsuitable rooting medium on planting sites.** Logically the places to plant trees after mining would be the kinds of places they grew before mining: along drainages; around lakes, ponds, and wetlands; and on steep slopes. These are topographic features typically not cleared and used for crop production. Similar topographic features with no expectation of growing crops are designated on permits. The coal companies have been required to replace "topsoil" (top dirt) on the topography obviously not usable for crops such as the steep banks of ramps leading to a strip mine lake. These slopes with massive, fine-textured soils have accelerated runoff that enhances erodability. In contrast, a minesoil with coarse fragments would form an erosion-resistant surface mulch. The coarse fragments would facilitate water infiltration and percolation and root growth, and would weather to release nutrients, thus greatly enhancing forest produc-tivity (Ashby *et al*. 1984). Unfortunately, even places uniquely destined for trees cannot be reclaimed with a suitable rooting medium.

   What justification is there for not allowing alternative, productive minesoils in these noncrop areas? Although not widely known, many reclaimed areas have been planted twice or even three times after massive failures. Of the acres planted to trees in Illinois in 1990, approximately 20 percent were replanted in 1991 and 10 percent in 1992.

   Is there a justification for restoring the predominantly highly weathered and leached soil fines of southern Illinois "prime farmland" soils that readily compact and are highly unsuited for long-term tree growth? When wet they are anaerobic and toxic, and when dry become indurated, like brick. The failure of roots to penetrate pan soils is complicated by nutrient deficiencies and unfavorable pH (USDA 1951). Compared to minesoils, they have much less potential for support of a vigorous sustainable forest ecosystem. Acceptance of alternative land uses agreeable to the land owner should not be controlled by so-called environmental groups or compliant county agents with no forestry background. Every soil is stony; the only question is what size rock, and what is magical or meaningful about the 2 mm size barrier? Soils with coarse fragments are commonly more productive than without, and become more productive as the fragments weather. Is SMCRA fulfilled by reclamation mistakenly carried out with degraded rather than renewed soils?

2. **Restricted selection of tree species able to tolerate restored fragipan soils.** Forest restoration in southern Illinois will have to be reinvented to cope with site conditions unlike those prelaw. The prevailing forest cover at settlement was cleared by early settlers, followed by loss of topsoil with unwise farming practices. Reclam-ation should recreate soils similar in productivity to those forested before the topsoil was eroded off.

   Tree species found to be successful on minesoils have died or grown poorly on restored topsoils. Much of the first 20 years under SMCRA was therefore spent in species trials to find out whether any of the species optimistically recommended in various reclamation manuals were indeed adapted to the new post-SMCRA rooting medium. New species have been added and are still being added for trial to the reclamation roster (Ashby 1996B).

   A unique forest type in which bottomland species predominate is being developed for the unique postmining upland soils in southern Illinois. Even though they are soils on the upland, they commonly are waterlogged after precipitation events so that oxygen becomes depleted and roots of most upland species die in the anaerobic rooting medium. Seedlings of baldcypress, pin and bur oak, green ash, and other lowland trees have to date been relatively most successful as a potential forest canopy.

   Bond release based on number of trees after five years is technologically feasible. No one knows if these species can continue to survive and grow on the restored upland soils. There are indications that woodlands with scattered trees rather than forests will be the final result. Has reforestation under SMCRA sec. 515 (b)(2) "restore the land affected to a condition which it was capable of supporting before any mining,..."or (19) "establish...a diverse, effective, and permanent vegetative cover of the same seasonal variety native to the area..." been fulfilled? Soil types in nature vary in a catena or chain with changes in topography, drainage, and vegetation. A diverse postmining vegetative cover requires diverse soils.

3. **Excessive runoff from compacted, fine-textured soils.** Excessive runoff on graded, easily compacted, fine-textured soils results both from lack of water movement and storage in the soils and from long, smooth slopes as shown in the universal soil-loss equation. Limited soil moisture recharge in such a soil accentuates drought stress. Potential soil erosion by surface runoff leads to other reforestation problems.

4. **Adverse water relations on restored prime farmlands.** The restored, fine-textured, massive prime farmlands do hold, and also keep holding, more water than minesoils (mixed overburden). Plant water uptake also is limited by failure of root-system development on saturated or brick-hard subsoils.

5. **Unsuitable and excessive ground cover on tree planting sites. Some recent improvement can be noted.** The absence of meso- and micro- topographic diversity on intensely graded, fine-textured soils together with excessive runoff leads to accelerated erosion and a consequent use of ground cover to control erosion. An absence of coarse fragments eliminates potential for stone surface mulches that retard runoff and provide micro-habitats for successful establishment of tree seedlings.

   Ground covers, primarily grasses and legumes, planted for erosion control typically are over-planted to ensure thick stands, and are highly competitive with juvenile tree seedlings. Adverse direct effects on tree growth of thick ground cover, especially with highly competitive species, include competition for soil water, allelopathy by which a plant poisons its neighbors, and reduction of available light for photosynthesis. There are favorable direct effects of thin ground cover especially with woodland herbs, including protection from excessive evapotranspiration with less wind movement and shading with moderated leaf and soil temperatures.

6. **Extensive and continuing damage from excessive animal populations with grass/legume ground covers.** Voles repeatedly have decimated tree plantings in fields with grass swards, in the 1980s and 1993 and 1994 locally. A year for bond release is lost each time. Rabbit nipping may eliminate some species. Grassy areas planted with trees that attract deer are likely to develop as shrubland or woodland rather than as productive forests. Deer damage includes browsing and buck rub and causes extensive tree mortality for some species (Ashby 1996C, 1997). Damaged trees with poor form and apparently healthy sprouts with increased incidence of disease and insect damage may lead to a woodland rather than a forest.

New or Revised Technology Tending to Foster Reforestation Success

1. **Recently increased availability of suitable planting stock from cooperating tree nurseries.** Availability of seedlings suitable for reforestation can be a major problem. During the prelaw government-industry cooperative program of planting an acre of trees for every acre mined, the state tree nurseries in Illinois supplied graded seedlings of requested species to the mining companies. That program ended and orders for trees from mining companies were the last to be filled if any seedlings were left. Desirable species became rarely available; seedlings were ungraded and, in most years, were received too late in the season for successful planting. The companies turned to private nurseries and found that needed kinds of seedlings were unavailable. In recent years, two large mining companies have contracted with a nursery to grow quality seedlings and the reforestation programs of those companies have shown noticeable improvement. Trained personnel that understand species selection and handling of tree planting stock are required for successful reforestation. Poor planting stock should be rejected or thrown away.

2. **Use of less competitive ground cover species.** Ever since the implementation of SMCRA, industry reclamation specialists as well as university research personnel have noted competitive ground cover as a significant limiting factor of tree seedling survival and growth (Ashby 1990). Commonly used pasture species

conspicuously limiting for tree survival were tall fescue (*Festuca elatior*) and alfalfa (*Medicago sativa*). They become even more limiting with higher fertility levels. Companies with experienced reclamation personnel now plant species such as redtop grass (*Agrostis gigantea*). Ground cover requirements could be relaxed to promote development of a tree canopy and litter with minor if any increase in erosion.

3. **Timing of planting ground cover and trees.** A key to success of tree plantings is rapid early growth. Seedlings that fail to get ahead of the ground cover typically have high mortality rates, slow growth, and greatly increased animal damage. Rapid growth results from planting ahead of or with a ground cover on well-drained, permeable soils. If a planting is delayed until ground cover is established, and especially if unsuitable ground-cover species are planted, prospects of successful tree planting for many species are very limited. This varies among tree species (Ashby *et al*. 1988). Knowledgeable reclamation personnel are needed to select species suitable for each site.

4. **Selected use of seed to extend planting opportunities.** As shown in tables 3, 4, and 5, tree planting with seed has been successful with red oak, black walnut, and other large-seeded species (Ashby *et al.* 1995, Ashby 1996C). Most small-seeded species are typically not successful. Planting trees as seed is uncommon in southern Illinois.

   Seed has the advantage of small bulk and tolerance to wide ranges of moisture and temperature for relatively long storage periods. Seed can thus be available for planting whenever soil and weather conditions are favorable. Please note that acorns and some other fleshy-seeded species are not tolerant to drying out, and must have storage conditions and planting seasons similar to those for seedlings.

   Disadvantages of seed differ with species. They include physiological lack of seed production (alternate-year bearing) found especially with oaks, loss of seed crops from late frosts and other adverse weather conditions, internal damage to seeds from insects and disease, animal use of seed including after planting, and lack of germination from varied causes. Many kinds of seed have dormancy processes that affect time of germination and require special handling by trained personnel.

5. **More skillful use of herbicides.** Herbicide applications to eliminate herbaceous cover typically greatly increase tree survival and to a lesser extent growth (Ashby 1997). Use of herbicides at or before tree planting has become almost standard procedure. If not repeated, ground cover closes in again after about two years.

   Repeated herbicide applications in research studies have given additional marked benefits up to canopy closure and are rarely, if ever, carried out by mining companies. Some tree species are sensitive to herbicides. More effective herbicides continue to come on the market and first-time use of a new herbicide can bring surprises. Timing of application is very important. Herbicide use must be carried out intelligently and carefully for environmental and safety reasons.

6. **Use of planting machines.** Planting machines are widely used and generally successful for initial establishment related to skill of operator, moisture conditions of soil, and suitability of available tree seedlings. The machines greatly cut down on labor requirements and speed up planting. In a recent survey, seven larger mines in southern Illinois contracted out planting operations and only one company owned a planting ma-chine. If because of prolonged wet soils planting by machine cannot be carried out and labor is not available, planting may have to be delayed a year. Wet fine-textured soils also may affect success of establishment if hand planting is used.

7. **Research and applications for remediation of AML sites.** Prior to the 1960s about ten percent of the mined acreage in Illinois was barren for a few to many years. If adjacent areas had acid-tolerant species such as river birch or pin oak, they invaded to form forested patches that coalesced in later years. The minesoil pH of such areas tended to converge toward values typical of regional soils (Davidson *et al*. 1988), and tree species less acid-tolerant later invaded. An unfortunate feature of AML reclamation projects has been the bulldozing of established trees to start over on graded, compacted soils with dense ground cover in which tree seedlings typically die. These AML lands are not prospective cropland needing such intensive reclamation. The best

management for many areas would be to let nature take its course of natural succession.

For cosmetic or other reasons these sites can routinely be reforested by applying limestone and planting adapted species. Having skilled personnel who know how to choose the right species to plant on a site is a fundamental rule for successful reforestation.

8. **Reclamation technology to recycle waste materials and reforest barren sites.** Forests with significant environmental and economic value have been created on barren sites by simultaneously disposing of otherwise waste material. In a 1975 cooperative USDA Forest Service, industry, and university reforestation project, sewage sludge was brought from the Chicago area to prelaw Palzo/Will Scarlet mine sites in Williamson County. Most tree species planted after sludge incorporation established well. Although some species later died out, after 15 years many of the plots had a well-developed forest cover (Van Sambeek *et al*. 1992).

   Studies of reclamation on landfills and mined lands have shown trees to be effective in ameliorating adverse conditions by sequestering toxic ions. Growth of other species and water quality are improved.

9. **Soil ripping or subsoiling including biological compaction mitigation.** I apologize for even bringing up ripping because it would not be needed with better reclamation practices. There are established techniques to return a mined area to approximate original contour (AOC) with minimal compaction. These include dragline pullback or truck haul with restricted traffic paths. Tree growth has been successful on such lands appropriately returned to AOC. Compaction also could be lessened if fine-textured soils are not segregated and returned as massive layers but rather with a mixture of coarse fragments.

   Where unfortunately needed, ripping of inherently massive, fine-textured, and/or compacted soils increases soil aeration and water entry and storage. We do not know how soon or how likely the rips will disappear as a homogeneous fine-textured soil mass flows together when saturated, or whether roots will later be able to grow beyond a rip furrow to support long-term biomass production. To some extent, ripping physically eliminates herbaceous ground cover competition along a soil rip. Tree seedling survival and root and top growth have increased greatly on ripped soils (Josiah 1986). Significantly greater height growth was found with ripping for red oak and black walnut after 12 years (Table 4) (Ashby 1996C). Both were planted as seed on graded, compacted minesoil with 40 percent coarse fragments greater than 2 mm in diameter.

   Conventional wisdom assumes deep-rooted plants are of value for opening root channels in compacted soils. Roots of a few tree species were found to be exceptionally able to penetrate deeply into compacted, fine-textured, restored soils (Ashby and McCarthy 1990). The most effective species in our study were baldcypress and hybrid cottonwood (*Populus* x), followed by sycamore. An ability of their roots to tolerate seasonally saturated/anaerobic soils may be the key to their deep-rooting. Alfalfa, deep-rooted on some soils, did not survive on the poorly drained soils (Raisanen 1982).

10. **Tree tubes and other planting techniques.** Tree tubes or shelters have given variable results. If damage from animal populations could otherwise be lessened, not likely these days, tree tubes may not be worth the cost and labor. Plastic mats a meter square around the base of a tree seedling seemed to be of little use (Ashby 1995).

    A plastic sheet having slits for water entry that covered a much larger planting area has given greatly increased survival and growth. Baldcypress, a swamp species that can tolerate saturated soils, is highly

    sensitive to ground cover competition otherwise eliminated by flooding on natural sites. Baldcypress seedlings on a tight, poorly drained, restored soil covered with a plastic sheet averaged 1.5 m tall after four years, and died out in an adjacent plot even with initial herbicide control of ground cover.

    Organic mulches—bark, sawdust, etc.—give variable results related to weather conditions, type of material, thickness, tree species, etc. Local testing and experience are recommended. As noted in section C.8, sludge and other waste products greatly increased tree survival and growth on barren sites. These materials vary greatly in local availability and quality and their use must be carefully monitored.

Broadcast fertilization on tree-planting sites is generally not recommended. Increases in herbaceous cover seem to offset benefits, if any, for tree growth. Fertilizer tablets that can be beneficial when properly placed in the ground around lawn trees have not seemed of particular benefit to seedlings in reclamation plantings.

Mycorrhizal fungi commonly have been found on tree roots of reclamation plantings, with spores evidently carried by wind, rain, or animals, and inoculation of seedling roots does not seem to be needed. Mycorrhizae make calcium, phosphorus, and other nutrients in coarse fragments available for tree growth.

Potential For Successful Reforestation

1. **Prelaw tree plantings on mixed overburden minesoils throughout southern Illinois were widely successful.** In Illinois prelaw, the coal associations voluntarily planted an acre of trees for each acre mined, and the Illinois Department of Conservation Division of Forestry grew the needed tree seedlings. These cooperative arrangements fulfilled the goal of successful reforestation deemed appropriate at that time to give us thousands of acres of productive forests today. A wide choice of high-quality tree species planted on minesoils for timber, wildlife, recreation, and other needs had good to excellent growth. The overburden of mined lands when suitably replaced had desirable physical and chemical properties for superior tree growth. Coarse fragments in the cast overburden rapidly weathered when brought near the land surface to form silt loam soils. Several studies by the USDA Soil Conservation Service (SCS, now NRCS) reported these soils to be deep and well-drained minesoils.

   Average height growth on the Sahara Coal Co., Inc. Mine No. 6 in Saline County of trees planted chiefly in the 1940s ranged in 1993 from 33 m for red/shumard oak, to 24 m for walnut planted as seed (Table 5) (Ashby 1996A). Similarly good growth was measured in Perry and Randolph counties in 1993.

   Growth of tree species planted in 1981 on mixed overburden mined pre-SMCRA in Saline County compared to the same lot of seedlings planted on replaced "topsoil" was without exception greater on the minesoil (Table 6). Black walnut, basswood, and especially tuliptree, ecological indicators of good to excellent drainage in their natural habitats, clearly show the limitations to tree growth of replaced "topsoil." Unlike corn, that is adapted for high yields with intensive management on a wide range of upland soils, any of these tree species is much more sensitive to inferior soil conditions and a better index plant for assessing soil quality.

2. **Cultural information has been available from manuals and other literature on need for suitable rooting medium, choice of species, planting practices, and other elements for success of tree plantings.** Prelaw and early postlaw, the USDA Forest Service had reclamation research centers (that have been eliminated) at Carbondale, Illinois; Berea, Kentucky; and other locations in the eastern United States. Part of their legacy, in addition to valuable long-term research plots, has been a substantial and valuable ongoing reclamation literature. Much resulting cultural information for successful reforestation with a suitable rooting medium has been available for 40 years (Limstrom 1960). Unfortunately, this type of information was overlooked or ignored in drafting SMCRA 15 years later.

   Users of these studies have included the USDI Office of Surface Mining (OSM) that over a period of years sponsored training sessions on reclamation including reforestation. Willis G. Vogel of the then Forest Service research office in Berea, Kentucky prepared for the OSM sessions *A Manual for Training Reclamation Inspectors in the Fundamentals of Soils and Revegetation*. This 1987 manual incorporated findings from Forest Service and university research and from coal company reforestation plantings in the eastern and western coal regions. Most of the available information, and all information for trees older than ten years, came from trees planted on minesoils before the passage of SMCRA that eliminated minesoils in favor of replaced fine-textured top dressings.

   In 1993, Ashby and Vogel published *Tree Planting on Mined Lands in the Midwest A Handbook*, related more specifically to midwest conditions and still largely based on pre-SMCRA minesoil tree plantings. Some earlier statements from the 1987 publication were modified based on post-SMCRA research findings. New sections were added on topics not earlier recognized to be of great importance in reforestation, for example extensive wildlife damage to tree seedlings planted in post-SMCRA grassy swards.

Although manuals based on longer-term tree growth on lands reclaimed under post-SMCRA regulations in southern Illinois are not available, numerous reforestation research papers have been published in conference proceedings and in reclamation or restoration journals. Trees planted post-SMCRA on restored prime farm-land are now sufficiently old for meaningful comparisons with trees planted much more successfully pre-SMCRA or contemporaneously on cast overburden minesoils from pre-SMCRA mining operations.

3. **The components for successful reforestation could readily be in place if the regulatory authorities would accept needed changes in reclamation requirements.** The mining industry could readily shift to successful reforestation if the regulatory authorities would remove barriers and offer incentives. There are still plenty of reforestation personnel able and anxious to bring about successful reforestation that could be recruited and entrusted with the job. The problem areas have been identified and should not longer be left unsolved. Suitable nursery stock, planting machines, herbicides, and other needs are available.

   Today planting of trees, if any, is contracted out to commercial operators. Some of these contractors try to do a very responsible job, while others are less qualified or committed. Selection and supervision of qualified contractors is very important. Mining company reclamation supervisors have learned to handle these operations and with additional personnel could expand operations greatly. Even at best, with millions of trees to plant in a short planting season, there can be problems of delays from unsuitable weather, poor seedling handling, inexperienced planters, etc. Just anyone cannot successfully plant large numbers of tree seedlings during each annual brief period with suitable temperatures and soil-moisture levels.

4. **Tree plantings established to date on several kinds of rooting media are an invaluable resource for ongoing research studies and projections.** Trees are long-lived. Questions of reforestation success or failure can only be answered decades after trees are planted. Bond is released five or more years after planting. How well is bond release correlated with long-term success? (This type of analysis should be carried out for corn farming as well.) Are rate of tree growth or other yield measurements needed for predictability of success? How serious is deer and other animal damage for forest development? How readily do other plant, animal, and microbial forest components invade to establish a self-sustaining ecosystem?

   The varied types of company plantings and research plots established since 1977 (SMCRA) can be studied to gain as much as 20 years in answering these significant questions. Many of these plantings are recorded and documented in the *National Register of Reclamation Research and Demonstration Areas on Mined Land* funded in large part by OSM (Ashby 1992).

Conclusions and Recommendations

If a regulatory authority wished to have more mined land planted to trees, what options or requirements are there to change present practices? SMCRA is charmingly innocent of specific provisions to require planting of trees. Since forestry is not otherwise designated in SMCRA, must it not be acknowledged as a higher or better post-mining land use to encourage tree planting? Are not forest trees a crop?

The Illinois Act in Section 3.15. Vegetation. (a) states "The Department may approve vegetation plans for the purpose of soil building..." Farming, row cropping as traditionally practiced in this country, constitutes low scale strip mining. The topsoil is progressively eroded off and surface mining later simply more drastically disturbs the remaining overburden of the worn-out fields. As considered elsewhere in this paper, forests are ideal for the long-term building from mixed overburden of a soil bank to support future agricultural needs.

The value of forests to control soil erosion, reduce stream pollution, enhance soil productivity, and sequester carbon has been recognized as a higher and better land use in the USDA Conservation Reserve Program (CRP). A means to encourage forestry would be for OSM's requirements to be in line with standards for success used by the USDA. Trees are planted on former croplands and Congress appropriates millions of dollars for conservation payments to farmers.

Under the present administration of SMCRA, mining removes forests to recreate marginal agricultural lands that after bond release presumably would again be eligible for CRP payments to plant trees. Why not directly reforest mined lands? If so, tree growth could be vastly improved by using not restored degraded soils typical of CRP worn-out fields but long-term rich and productive postmining soils from mixed cast overburden. Mined lands are ideal for large blocks of forest to reduce edge effects and cowbird predation of song bird reproduction. Mineland forests have been refuges for endangered species.

These needed changes have not been authorized and supported. The experimental practices provisions of SMCRA clearly encouraged soil-building demonstrations. Our national goal should be to restore the type of naturally rich and productive forest soils that once existed in premining areas. Restoration to that level of productivity requires mixing of mineral-rich coarse fragments from lower in the overburden with the top-dressing materials currently replaced.

If past is prologue, prospects for effective reforestation on surface-mined lands in southern Illinois are dim indeed. How to grow trees is not a major problem. Just as the best technology in the world has yet to produce a car that would run or a plane that would fly without fuel, so effective reforestation is dependent on a suitable rooting medium.

The powers-that-be in Illinois seem not even to have considered what is a suitable rooting medium for reforestation. Soil science, SMCRA, and common sense are flouted to restore the local relatively unproductive "prime farmlands." Producing an occasional acceptable corn crop at great cost only proves that corn can be grown on any nonflooded soils. My research group (ms in preparation) has successfully grown corn on minesoils (mixed cast overburden). This type of study of minesoil productivity should be tested and, when proved, implemented to benefit both crop and forest productivity.

Once major blockages to successful reforestation are removed, trained reclamation personnel are available that mining companies have on staff or could rehire to meet those needs. There also is suitable talent and experience in Mines and Minerals that could work cooperatively with industry reclamation personnel toward a common reforestation goal. The cooperative relations prelaw between government and industry for successful reforestation should be restored. The goals of SMCRA are not unattainable. More attention to creativity and less emphasis on unwarranted restrictions are needed.

Literature Cited

Ashby, W.C. 1990. Factors limiting tree growth in southern Illinois under SMCRA. Proceedings 1990 Mining and Reclamation Conference and Exhibition, Charleston, West Virginia. pp. 287-294.

Ashby, W.C. 1992. National Register of Reclamation Research and Demonstration Areas on Mined Land. Coal Research Center, Southern Illinois University at Carbondale. 83 p.

Ashby, W.C. 1995. Plastic sheets and tree tubes for reclamation with trees. International Journal of Surface Mining, Reclamation and Environment 9(1995):165-167.

Ashby, W.C. 1996A. Growth of hardwoods and conifers after 47 years on coal mine soils in southern Illinois. Tree Planters' Notes 47(1):24-29.

Ashby, W.C. 1996B. Trees chosen for reclamation in southern Illinois, USA. International Journal of Surface Mining, Reclamation and Environment 10(4):167-168.

Ashby, W.C. 1996C. Red oak and black walnut growth increased with minesoil ripping. International Journal of Surface Mining, Reclamation and Environment 10(1996):113-116.

Ashby, W.C. 1997. Soil ripping and herbicides enhance tree and shrub restoration on stripmines. Restoration

Ecology:5(2)169-177.

Ashby, W.C. and J.R. McCarthy. 1990. Compaction mitigation using plant materials. Y.P. Chugh, D.C. Davin, and K.R. Dietz, eds., Proceedings First Midwestern Region Reclamation Conference, Coal Research Center, Southern Illinois University at Carbondale. pp. 7/1-7/14.

Ashby, W.C. and W.G. Vogel. 1993. Tree planting on mined lands in the midwest: a handbook. Coal Research Center, Southern Illinois University, Carbondale, Illinois 62901. 115 p.

Ashby, W.C., C.A. Kolar, G.R. Philo, and C.A. Huetteman. 1995. Database of reclamation with trees in southern Illinois, 1978-1993. Coal Research Center, Southern I,linois University at Carbondale. 47 p.

Ashby, W.C., M.R. Norland, and D.A. Kost. 1988. Establishment of trees in herbaceous cover on graded Lenzburg minesoil. Mine drainage and surface mine reclamation, vol. II: Mine reclamation, abandoned mine lands and policy issues. Bureau of Mines Information Circular 9184. pp. 48-53.

Ashby, W.C., W.G. Vogel, C.A. Kolar and G.R. Philo. 1984. Productivity of stony soils on strip mines. Erosion and Productivity of Soils Containing Rock Fragments, Soil Science Society of America, Madison, Wisconsin. pp. 31-44

Davidson, W.H., W.C. Ashby, and W.G. Vogel. 1988. Progressive changes in minesoil pH over three decades. Mine Drainage and Surface Mine Reclamation, vol II: Mine Reclamation, Abandoned Mine Lands and Policy Issues, Bureau of Mines Information Circular 9184. pp. 89-92.

Grossman, R.B., J.B. Fehrenbacher, and A.H. Beavers. 1967. Fragipan soils of Illinois: I. General characterization and field relationships of Hosmer silt loam. Drew, J.V., ed. Selected papers in soil formation and classification. Soil Science Society of America, Inc., Madison, Wisconsin. pp. 41-52

Illinois Department of Mines and Minerals. 1980. The Surface Coal Mining Land Conservation and Reclamation Act. Springfield, Illinois. 70 p.

Illinois Department of Mines and Minerals. 1993. Citizen's Guide to Coal Mining and Reclamation in Illinois. Springfield, Illinois. 31 p.

Josiah, S.J. 1986. The effects of minesoil construction techniques and ripping on the long-term survival and growth of black walnut. Proceedings American Society for Surface Mining and Reclamation National Meeting, Jackson, Mississippi. pp. 183-193.

Kohnke, H. 1968. Soil Physics. McGraw-Hill, New York. 224 p.

Limstrom, G.A. 1960. Forestation of strip-mined land in the central states. USDA Agriculture Handbook No. 166. 74 p.

Public Law 95-87. 1977. Surface Mining Control and Reclamation Act of 1977. 91 Stat. 95th Congress, Washington, DC. pp. 445-532.

Raisanen, D.L. 1982. Survival of selected tree species on sites reclaimed to various reclamation standards. 1982 Seminar: Post-Mining Productivity with Trees. Carbondale: Southern Illinois University. pp. 92-102.

U.S. Dept. Agriculture. 1951. Soil Survey Manual. Agriculture Handbook No. 18. USDA, Washington, DC. 503 p.

Van Sambeek, J.W., W.C. Ashby, and P.L. Roth. 1992. Performance of trees and shrubs on sludge-amended acidic minesoils. Proceedings of the 9th Annual National Meeting of the American Society for Surface Mining and

Reclamation, Duluth, Minnesota. pp. 587-592.

Vogel, W.G. 1987. A manual for training reclamation inspectors in the fundamentals of soils and revegetation. Soil and Water Conservation Society, Ankeny, Iowa. 178 p.

____

[1]Dr. Ashby holds a B.S. in Ecology, PhD in Botany and Plant Physiology from the University of Chicago. He also did graduate work at the University of California in genetics and crop production. Previously he was a Plant Physiologist with U.S. Forest Service, a Research Fellow at California Institute of Technology, and a Fulbright Scholar at Sydney University in Australia doing research on plant/soil relations. He was an Assistant Professor of Forest Ecology at the University of Chicago. More recently he served as Professor and Professor Emeritis of Botany at Southern Illinois University, Carbondale.

Table 1. Factors that foster and hinder reforestation acreage and success.

A. External technological factors tending to constrain reforestation acreage and success
1. Forestry omitted in regulations
2. Lack of criteria for forests
3. Forest acreage omitted on permits
4. Incompatible reclamation goals

B. Technological factors tending to constrain reforestation success
1. Unsuitable reforestation soils
2. Compacted rooting zones
3. Excessive runoff
4. Adverse water relations
5. Unsuitable/excessive ground cover
6. Excessive animal damage

C. New or revised technology tending to foster reforestation success
1. Better planting stock
2. Less competitive ground cover
3. Timely planting operations
4. Demonstrated seed potential
5. Improved use of herbicides
6. Use of planting machines
7. Remediation of AML sites
8. Recycling of waste resources
9. Remedies for compaction
10. Tree tubes, plastic mulches, misc.

D. Potential for successful reforestation with suitable rooting medium
1. Successful plantings prelaw
2. Available reforestation literature
3. Latent reforestation potential
4. Legacy of research plots

Table 2. Pre- and postmining acreages of forest and wildlife habitat for two mining permit submittals in southern Illinois.

Permit Acreage	Forest Areas: Mined		Forest Areas: Support		Wildlife[a] Areas: Mined		Wildlife[a] Areas: Support	
	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
1500[b]	89	0	154	154	54	197	103	132
2402[c]	352	0	24	24	(4)[d]	343	(4)[d]	359

[a] Vegetation type not specified
[b] 1022 acres must be reclaimed to crops as Prime Farmland
[c] 1216 acres must be reclaimed to crops as Prime Farmland
[d] 4 acres total premining wildlife

Table 3. Species survival and height on four kinds of rooting medium at age 12 years, or 13 years if *. The bolded numbers in each row are the greatest survival or height.

Species	Survival (%)				Height (m)			
	Cast	Graded	Topsoil	Place	Cast	Graded	Topsoil	Place
Sweetgum *Liquidambar styraciflua*	31	1	66	**78**	6.7	3.0	4.5	**6.8**
River birch *Betula nigra*	46	4	26	**48**	**7.3**	4.9	4.3	4.6
Sycamore *Platanus occidentalis*	76	17	52	**98**	**7.9**	6.2	4.1	7.2
Bur oak* *Quercus macrocarpa*	75	**90**	28	47	**4.5**	3.7	3.4	2.0
Red oak *Quercus rubra*	66	19	**87**	78	**5.2**	1.9	3.4	2.2
White ash *Fraxinus americana*	59	62	86	**98**	3.7	**4.1**	3.3	4.0
White oak SD *Quercus alba*	**61**	4	34	4	**3.9**	1.3	2.9	1.3
Black oak* *Quercus velutina*	**31**	21	1	17	3.7	2.1	2.7	**3.9**
Shumard oak SD *Quercus shumardii*	44	16	**72**	59	**4.7**	1.7	2.6	2.3
Red oak SD	43	1	**70**	58	**5.5**	1.4	2.6	1.2
White oak	57	20	**84**	80	**3.8**	2.0	2.5	1.6
Pin oak *Quercus palustris*	47	8	**93**	84	**4.8**	2.7	2.4	1.4
Silver maple *Acer saccharinum*	47	17	**52**	87	**6.0**	5.2	2.4	3.7
Baldcypress *Taxodium distichum*	33	0	79	**92**	**2.7**	died	2.1	2.3
Persimmon *Diospyros virginiana*	18	8	76	**83**	**3.6**	2.0	1.7	2.2
Black walnut* *Juglans nigra*	57	**71**	8	19	**3.7**	3.0	1.5	0.9
Black walnut SD	11	49	80	**93**	**4.1**	**4.1**	1.0	2.5
Tuliptree *Liriodendron tulipifera*	19	0	5	**64**	**6.0**	died	0.7	4.7
Basswood *Tilia americana*	**79**	29	73	23	**4.0**	3.4	0.5	1.0
	Cast	Graded	Topsoil	Place	Cast	Graded	Topsoil	Place
# **Bolded**	**3**	**2**	**6**	**8**	**16**	**2**	**0**	**2**

Table 4. Effects of ripping on growth of 13-year-old red oak and black walnut planted as seed on graded cast overburden.

Species	Survival (%) Ripping -	Survival (%) Ripping +	Heights (m) Ripping -	Heights (m) Ripping +
Red oak SD	8	61	2.2	4.5
Black walnut SD	38	69	2.6	5.5

Table 5. Age in years and height growth of tree seedlings or seed planted on ungraded cast overburden chiefly in the 1940s and measured in 1993.

Species	Age	Height (m)	Species	Age	Height (m)
Red/Shumard oak	55	33	Sweetgum	47	26
Tuliptree	40	30	White oak	55	26
Black walnut	47	27	Black walnut SD	47	24

Table 6. Average height (m) of six hardwood tree species 13 years after being planted on "topsoil" and on minesoil.

Species	Height (m) "Topsoil"	Height (m) Minesoil
Sweetgum	3.9	7.1
White oak	3.5	3.9
Red oak	3.2/2.2[a]	5.0/5.0[a]
Black walnut	1.5/0.9[a]	3.7/5.3[a]
Basswood	0.6	3.7
Tuliptree	died	4.6

[a]Planted as seedlings/seed.

LOW MINE SOIL COMPACTION RESEARCH

Donald H. Graves[1], Interim Chair
Department of Forestry, College of Agriculture, University of Kentucky
Lexington, Kentucky

Abstract

A multidisciplinary group of researchers at the University of Kentucky initiated a diverse study to evaluate the effects of soil compaction on the survivability and growth of high value tree species. This study was established on the Starfire Mine owned by Cyprus-Amax in Perry County, Kentucky. The team of researchers encompassed the various expertise areas in the departments of agricultural engineering, forestry, mining engineering, and ecology.

Since its initiation, a weather station has been established, over 57,000 trees have been planted, a passive dewatering system initiated, and a fertigation study constructed. The trees consisting of seven species have been planted on areas that were compacted, partially compacted and uncompacted.

Bulk densities and penetrometry data have been gathered on all the planted sites to determine the relative compaction of each planting area. Compaction is already a contributing factor to either or both tree survival and growth.

Additional studies being conducted include the effects of alternative ripping methods on reclaimed areas that were compacted in the normal manner prior to the concept of a new grading standard. These plots were mulched and planted this month. Additional studies will be planned depending upon the availability of funds.

Introduction

The University of Kentucky Department of Biosystems and Agricultural Engineering, Department of Forestry, and Department of Mining Engineering began an extensive reclamation research project in 1995. This project is intended to extend the efforts of past and ongoing research programs at the University of Kentucky, Southern Illinois University, and VPI's Powell River project. It also was designed to be an integrated effort that would utilize as many areas of expertise as possible.

The basis for justifying this research was the established facts presented by the Kentucky Reclamation Association that they had reclaimed 187,000 acres since 1948. Prior to 1980, 101,000 acres were planted primarily to trees. Since 1980, 86,000 acres were reclaimed with 1,500 acres being a return to forest land. Most of the area returned to forest land does not meet minimum stocking standards. Three thousand acres were planted to shrub species. The result has been the establishment of 81,500 acres of lespedeza and tall fescue.

Early research at Southern Illinois University found that by simply striking off old prelaw strip mine spoils created areas that resulted in the highest site index areas in the state for yellow poplar, white oak, and walnut. VPI (The Powell River Project) reported that applications of uncompacted spoil at a depth of 12 inches resulted in a white pine site index of 60 while 4 feet resulted in a site index of over 100. The result would be that an acre at site index 60 would be worth $100 in 30 years while an acre at site index 100 would be worth over $2400 at the same age.

Since the project was initiated the total area impacted has grown to approximately 83 acres. These include nine 3-acre cells that contain twenty one 1/10-acre plots that are comprised of seven species replicated three times. The cells consist of three that are compacted in the normal manner that has been accepted since the initiation of PL95-87. Three were back-dumped and left ungraded and three were back-dumped and "lightly graded." Lightly graded depended on how closely the dozer operator was supervised in the process.

One cell in each grading treatment was mulched with 45 ton per acre of hardwood bark, one mulched with 45 ton per acre barn litter, and one was left unmulched. Berms were constructed around each cell to contain all rainfall and eliminate any runoff that might be construed as detrimental to any surrounding area.

A fully automated recording weather station was placed on the research site. A passive dewatering sediment pond was constructed adjacent to the three compacted cells. All precipitation from the cells was diverted through the dewatering structure and recorded.

Additionally, a 1.5-acre area has been created to study sedimentation and a two-acre area to evaluate trickle irrigation and infiltration. These also have been mulched and planted with trees. To study methods of modifying existing reclaimed mine spoil to facilitate productive tree growth, six 2.5-acre cells have been mechanically ripped. Three were cross-ripped on approximately 6 foot centers to a depth of 30 inches or more. Three were ripped with conventional multitined rippers at a depth less than one foot. These areas were mulched as the other cells and planted with the same seven species replicated three times.

Additionally, a 20-acre area of moderately graded to ungraded dragline spoil was planted to simulate the planting systems common prior to PL95-87. These installations provide data that range from the completely ungraded to that completely compacted with additional information concerning the redisturbance of compacted sites.

To date approximately 57,000 trees have been planted with more planned, depending on availability of resources, for further expansion of treatment modifications. Equipment has been designed to make more radical modification of previously reclaimed areas, but we have not had the resources to initiate trials using the system.

Rick Sweigard will discuss the bulk density and penetrometer data that is being gathered on these areas. Tree survival and growth information is being correlated to the density measurements that are found with each treatment.

We have had to install 2.5 miles of high tensil electric fences to prevent cattle, deer, and elk damage to the trees. An additional 1.5 miles will be necessary this year.

Results

This project is expected to continue for 20 years or more. It is now in its infancy but beginning to yield some interesting results. In the uncompacted dragline spoil after three years, white ash has an average survivability of 91 percent and has averaged 24 cm of height growth. Yellow poplar is the least successful survivor with an average of 44 percent and walnut has only averaged 1 cm of height growth.

In the compacted dragline spoil, white ash still has a survivability rate of 87 percent. White ash and northern red oak have averaged 7 cm of height growth. Yellow poplar averaged only 13 percent survivability and walnut averaged a negative 7 cm of height growth during the three years. Negative height growth is a result of dieback and browse damage.

Survival in the loose-dumped cells after three years are very good. White ash averages 88 percent but is closely followed by northern red oak, yellow poplar, and white pine. Paulownia averaged only 37 percent survivability. This survivability can primarily be attributed to the planting stock. Those paulownia that survived averaged 47 cm of height growth. White ash had averaged 11 cm of height growth after two years. Black walnut averaged a negative 1 cm after two years. The overall survival averaged 76 percent with 11 cm height growth.

Black walnut was the leading average survivor in the rough-graded cells at an average of 92 percent followed closely on white ash. The lowest survivability was paulownia with an average of 48 percent. Paulownia height growth averaged 52 cm for the two years, and white ash averaged 13 cm. Black walnut averaged a negative 10 cm of height growth while the northern red oak averaged a negative 1 cm. The overall survival of these cells was 74 percent and had an average growth of 9 cm. White ash was the leading survivor in the compacted cells averaging

87 percent. The lowest survival was again paulownia which averaged only 11 percent. The surviving paulownia height growth averaged 33 cm for the two years, while black walnut averaged a negative 28 cm over the same period. The average survival in these cells was 45 percent and averaged a negative 1 cm for two years with ash

being the only species with a positive growth other than paulownia.

When we look at the average survival from 1996 to 1998 in the loose dragline spoil, we see that northern red oak, yellow poplar, and black walnut are slowly declining. White oak, white ash, and white pine are showing increases from resprouting dieback or browse. On the compacted dragline spoil only black walnut is increasing after initial dieback or browse damage. White ash resprouted and then declined the next year. Northern red oak is decreasing each year, while white oak, yellow poplar, and white pine are holding their own after the initial mortality.

Survivability is decreasing slowly in the loose-dumped cells for every species except paulownia and black walnut. In the rough-graded cells, all species are declining except white oak and black walnut. The survivability of all species are decreasing in the compacted cells.

The average height growth was greater for all species in the uncompacted dragline spoil, except white oak. The compacted cells resulted in a decreased height growth for all species. Greatest height growth averages were attained in rough-graded areas by white ash, paulownia, and white oak. White pine, walnut, yellow poplar, and northern red oak appear to prefer the loose-dumped cells.

Conclusion

There are some very positive trends beginning to appear in the data from this research area. There is not much doubt that compaction has a very negative effect on both survival and growth for the species selected in this study. We are seeing at this time that light compaction is not detrimental to some species at this stage of development. We also see that no compaction is beneficial to those species not affected by light grading. Time will be the determinate of which system works best but evidence from past research indicates that growth, yield, and soil formation are increased by either having little or no compaction by heavy equipment and are, in fact, better than undisturbed areas since more root development depth is attained than in normal natural stands.

____

[1]Dr. Graves holds a B.S. in Forestry from Purdue, an M.S. in Forestry from the University of Florida, and a Ph.D. in Agricultural Forest Economics from the University of Kentucky. He has been at the University of Kentucky since 1964. Currently, he is the Chairman of the Forestry Department. He has served with distinction on many task forces and committees and played a significant role in Kentucky's Reforestation Initiative. He has authored and contributed to numerous publications related to reforestation of mined lands.

USE OF FIELD MEASUREMENTS TO PREDICT REFORESTATION SUCCESS

Richard J. Sweigard[1]
Professor and Chair
and
Paul Bluestein
Research Assistant
University of Kentucky, Department of Mining Engineering
Lexington, Kentucky

Abstract

Measurements of dry bulk density and penetration resistance have been made on nine reforestation test cells at the Star Fire Mine in eastern Kentucky. Both properties are indicators of soil compaction. Dry bulk density was measured using a density gauge. Penetration resistance was determined using a recording cone penetrometer. This technology, which was developed for prime farmland soils, has produced useful data in terms of average penetration resistance (an indirect measure of soil strength). Both dry bulk density and penetration resistance results have been compared to tree survival rates on the various cells. It is believed that such measurements will ultimately be useful in predicting tree survival rate and site index for reclaimed surface mined land.

Introduction

It has been known for some time that excessive soil compaction is detrimental to the establishment of forests with high-value tree species. Due to the amount of grading involved, current reclamation practices in the central Appalachian region typically result in a highly compacted surface that inhibits root growth and development. These conditions lead to high mortality rates for seedlings planted on reclaimed surfaces.

Upon removal and replacement, the soil is compacted with earthmoving equipment to the extent that the original structure is destroyed. A crust is typically found on the surface layers due to final grading and leveling of the soil. There are no apparent lines of weakness with the exception of desiccation cracks near the surface due to wetting and drying. This reduces water infiltration and transmission through the soil. Layers of extremely compacted soil develop at various levels in the profile due to the intensity of traffic. The pore space is greatly reduced by the loss of macropores. These factors combine to produce a soil with poor physical properties that inhibits root growth (Dollhopf and Postle, 1988). Soil compaction is an inevitable result of soil transportation due to the breakup of its structure.

Several soil properties change as a result of soil compaction. Soil density increases as the soil particles move closer together. The mechanical resistance to penetration increases, depending on moisture content and size of soil grains. The hydraulic conductivity is reduced due to an increase in compaction (Barnhisel, 1988). These changes occur as a consequence of soil movement and restoration. Mine soils generally show little or no structure throughout their profile. Structure may begin to appear in mine soil within 50 years (Dollhopf and Postle, 1988).

Bulk density is a common method used to measure compaction of the soil. Freitag (1971) reviewed methods of measuring bulk density. Wet bulk density is defined as total mass per unit volume and is expressed as g/cm^3 (lb/ft3). Due to varying moisture content, this is rarely reported. Dry bulk density is defined as the dry soil weight divided by wet volume and is expressed as g/cm^3 (lb/ft3) and will be referred to as “bulk density “ or “density.” This value is typically reported in compaction studies. A low bulk density value corresponds to a less compact soil. As the bulk density increases, the soil particles come closer together. Smaller particles start to fill in the voids between the larger particles. Bulk density measurements may be taken gravimetrically or with a nuclear device.

Manufacturers of nuclear devices provide operational and scientific information for measuring bulk density (CPN Corporation, 1988). Radioactive methods measure in situ bulk density and utilize two forms of radiation: gamma and neutron. The unstable isotopes contained within the source will slowly decay to a more stable state. This act of decay produces emissions of energy as the atoms disintegrate. Two types of gauges are available: single probe and dual probe. The dual probe nuclear gauge contains two source isotopes in one probe (one emits gamma; one emits neutron radiation). The gamma radiation detector is located in the other probe, while the neutron radiation detector is located in the source probe. The single probe gauge also contains two source isotopes, but both detectors are located at the base of the instrument, which remains on the soil surface. Due to decay of the radioactive sources over time, new standards were established to calculate the soil count ratio, which is used in bulk density determinations (CPN Corporation, 1988).

Soil strength is related to mechanical resistance and is defined as "the ability or capacity of a particular soil in a particular condition to resist or endure an applied force" (Gill and Vandenberg, 1968).

Resistance to penetration depends upon soil properties such as texture, mineralogical composition, moisture content, and density. A coarse-grained soil will have a large average pore diameter and a low resistance to penetra-tion. A soil with a well-developed structure will contain macropores, which can easily be penetrated. Soils with a high moisture content have a lower resistance to penetration than a soil with lower moisture content. Generally, soils with a low bulk density have lower resistance to penetration (Thompson, Jansen, and Hooks, 1987).

A common method used to measure the soil's resistance to penetration requires forcing a shaft with a cone-shaped tip into the soil. In addition to the above mentioned items, the mechanical resistance encountered also depends upon the interaction of the soil with the cone. This includes the cone's diameter and angle, material of composi-tion, and rate of advancement. Since there are many factors affecting the resistance of penetration, this index can be used only when all other factors are held constant (Vomocil, 1957).

The mechanics of soil failure during penetration include shear failure, plastic flow, and compression. Direct interpretation of the penetrometer results in terms of soil strength is currently unavailable. However, the penetration resistance is considered to be related to the strength of the soil and is termed penetrometer soil strength (Hillel, 1980).

Field Study

An investigation was initiated at the Star Fire Mine in Perry County, Kentucky to study the impacts of varying degrees of compaction on tree growth. Research plots were constructed as follows: (1) three with loose-dumped spoil and no grading; (2) three with moderate grading to strike-off the tops of the spoil piles; and (3) three that were graded to a smooth surface typical of current surface mine reclamation practices. The three cells in each group then received different surface treatments: (1) one cell received bark mulch; (2) one received composted straw and horse manure; and (3) a control cell received no surface treatment. All nine cells were planted with seven hardwood species located in 21 randomly placed plots.

Field measurements were taken initially during the summer of 1997 on each of the nine cells. Resistance to penetration was measured with a custom-built, constant-rate recording cone penetrometer. The penetrometer was advanced until refusal. The depth to refusal and the average resistance over that depth were recorded. Two dry bulk density measurements were taken at each location. One was taken at the maximum depth of penetration achieved by the penetrometer and another measurement was made at a depth of two inches in each hole.

Penetrometer and bulk density measurements were taken at 28 locations in each of the nine cells. A second complete set of measurements was taken during the summer of 1998.

A recording cone penetrometer was obtained from the Southern Illinois University/University of Illinois Cooperative Reclamation Research Station. General design specifications for the penetrometer can be found in Hooks and Jansen, 1986. The fabrication began with a three point tractor-mounted Giddings soil coring machine.

The hydraulic system allows a constant penetration rate to be set. A load cell and computerized data acquisition system allow the penetration resistance to be measured over the depth penetrated. The machine is capable of penetrating to a depth of 50 inches; however, due to the rocky nature of the spoil at the site, much shallower depths were realized. This technology was originally developed for use on prime farmland. Figures 1 and 2 illustrate the different types of resistance profiles typically obtained for midwestern prime farmland and appalachian mountaintop removal sites, respectively.

Bulk density measurements were obtained using a CPN Model MSLA-OOA nuclear gauge. Gamma and neutron radiation is emitted from 10 mCi Cs-137 and 50 mCi Am-241/Be sources. The gauge has dual probes with a maximum penetration depth of 36 inches. One probe houses the radioactive sources and the other probe contains the sensors. Standard one-minute readings were used in all cases.

The penetrometer and density data were compared to the tree survival data that were obtained after each growing season. The tree data were taken by researchers from the Department of Forestry and the soil properties were measured by researchers from the Department of Mining Engineering. Tree survival data from two growing seasons have been compared to soil properties measured during those years. The field investigation is ongoing and additional data sets will be collected.

First Year Results

The compiled results by cell for the first year are given in Table 1.

Cells #2, #3, and #4 were uncompacted; cells #5, #6, and #1 were moderately compacted or graded lightly; and cells #7, #8, and #9 were fully compacted. The average depth to refusal, average penetration resistance, and average dry bulk density for the three conditions are listed in Table 2. The tree survival rate for each of the cells is given in Table 3. It can be seen from tables 1 and 2 that there is a recognizable difference in average penetration resistance, depth to refusal, and dry bulk density between the uncompacted, light graded, and compacted cells. As expected, the uncompacted cells (#2, #3, #4) had the lowest average penetration resistance (742psi), the deepest average depth to refusal (1.41ft), and the lowest average dry bulk density (91.3pfc). The lightly graded cells (#1, #5 #6) had intermediate values of 851psi for average penetration resistance, 1.13 ft for average depth to refusal, and 94.5 pcf for dry bulk density. The compacted cells (#7, #8, #9) represented the other extreme with an average penetration resistance of 1094psi, average depth to refusal of 0.97 ft, and average dry bulk density of 102.6 pcf. These findings are very important because they validate the assumption that these parameters can be used to quantify these parameters for the central appalachian region. At the present time, the data are not sufficient to draw any conclusions about the differing mulch applications that were used on the various cells.

Figure 3 illustrates the composite impact of surface condition on first year tree survival. Although there was not much difference between uncompacted and lightly graded cells, the compacted cells had a much lower survival rate. Figures 4 and 5 show survival rate as a function of refusal depth and average penetration resistance, respec-tively. A very interesting observation can be drawn from Figure 5-Survival Rate vs. Resistance to Penetration. The data seem to indicate that survival rate declines very slightly as average resistance increases up to some point. Preliminarily, this point appears to be around 1050 psi. However, at resistance above this level, survival rate decreases dramatically.

Second Year Results

The analysis of the second year results are not yet complete; however, some preliminary observations are possible. One of the objectives of the study was to see how mine soil properties change over time as a result of weathering and root penetration. The initial results are somewhat confusing. Figures 6, 7, and 8 show the bulk density, average penetration resistance, and depth to refusal, respectively, for the two years. The same measurement techniques were used for both years.

While it was anticipated that penetration resistance would decrease gradually over time, the large decrease from one year to the next is puzzling (Figure 7). Likewise, the reduction in refusal depth is difficult to explain in light of the reduction in penetration resistance (Figure 8). The dry bulk density measurements reported are taken at the two-inch depth. The results from the second year indicate a slight increase in bulk density at that depth.

A graph of tree survival rate as a function of average penetration resistance for the second year is given in Figure 9. Although the shape of the graph is generally similar to the one from the previous year, the data do not exhibit that same sharp cutoff point that was observed from the first set of data. It must be emphasized that these data were tabulated very recently and, as such, have not been thoroughly checked for calibration errors.

Conclusion

It is important to understand that this is work in progress and final conclusions cannot be drawn at this point. Some initial data were very encouraging that a simple relationship may exist between average penetration resistance and tree survival rate.

The second year results were less dramatic in regard to survival rate as a function of average penetration resistance. The changes in penetration resistance and refusal depth from one year to the next are currently unexplained. Subsequent measurements should indicate whether this is a real trend or simply a load cell recalibration issue.

No attempt has been made at this time to relate these physical properties of the soil to site index. This is certainly an objective; however, the data is too sketchy at this point to make this kind of projection. While there are certainly some interesting results to date, the primary conclusion is that additional data sets must be collected over the next several years to produce the kind of predictive tool that is desired.

References

Barnhisel, R. I., 1988, Correction of Physical Limitations to Reclamation", Reclamation of Surface-Mined Lands, Hossner, L. R., ed., Vol. 1, CRC Press, Inc., Boca Raton, Florida, pp. 192-211.

CPN Corporation, 1988, Tech Manual TM-1 Radiation Safety, Operating Procedures and Technician Maintenance, CPN Corporation, Martinez, California, 8 pp.

Dollhopf, D. J., and Postle, R. C., 1988, "Physical Parameters that Influence Successful Mine Soil Reclamation", Reclamation of Surface Mined Lands, Lloyd R. Hossner, Vol. 1, CRC Press, Inc., Boca Raton, FL, pp. 93-99.

Freitag, D. R., 1971, "Methods of Measuring Soil Compaction", Compaction of Agricultural Soils , American Society of Agricultural Engineers, St. Joseph, Michigan, pp. 47-103.

Gill, W. R., and Vanden Berg, G. E., 1968, Soil Dynamics in Tillage and Traction, Handbook No. 316, U.S. Government Printing Office, Washington, DC, 511 pp.

Hillel, D., 1980, Fundamentals of Soil Physics, Academic Press, Inc., San Diego, 413 pp.

Hooks, C. L., and Jansen, I. J., 1986, Recording Cone Penetrometer Developed in Reclamation Research, Soil Sci. Soc. Am. J., 50:10-12.

Thompson, P. J., Jansen, I. J., and Hooks, C. L., 1987 "Penetrometer Resistance and Bulk Density as Parameters for Predicting Root System."

Performance in Mine Soils", Soil Science Society of America Journal, Vol. 51, No. 5, September-October, pp.1288-1293.

Vomocil, J. A., 1957, "Measurement of Soil Bulk Density and Penetrability: A Review of Methods", Advances in Agronomy, Vol. 9, pp. 159-175.

---

[1]Richard Sweigard holds a Ph.D. in Mining Engineering and M.S. in Geology from Pennsylvania State University. He received his B.S. in Civil Engineering from Drexler University. As an Assistant Professor of Mining Engineering at Southern Illinois University, Carbondale, he had a research focus on surface mining reclamation and environmental effects of mining. He is a registered professional engineer in the state of Pennsylvania.

Table 1. 1997 Soil Properties for Each Cell.

cell #	Depth to Refusal (ft)	Dry Bulk Density (pcf)	Average Penetration Resistance (psi)
1	0.82	97.4	861
2	1.32	92.2	720
3	1.6	88.1	709
4	1.31	93.6	798
5	0.98	90.8	935
6	1.6	95.2	758
7	1.06	106.0	1122
8	0.91	98.2	1102
9	0.92	103.5	1057

Table 2. 1997 Average Soil Properties for Each Surface Condition

	Depth to Refusal (ft)	Dry Bulk Density (pcf)	Average Penetration Resistance (psi)
Compacted	0.97	102.6	1094
light graded	1.13	94.5	851
Uncompacted	1.41	91.3	742

Table 3. Survival Rate of Tree Species.

Survival Rate of Tree Species in Percent									
	BW	PA	RO	WA	WO	WP	YP	Average	
Cell									
1	95	38	91	94	91	87	92	84	SO
2	95	55	93	89	90	92	90	86	UC
3	98	50	100	92	94	95	95	89	UC
4	97	17	97	99	87	85	94	82	UC
5	96	45	94	99	93	87	97	87	SO
6	97	72	99	97	96	83	94	91	SO
7*	0	15	52	82	21	14	15	28	C
8*	29	25	96	97	53	15	41	51	C
9	95	25	100	95	91	82	98	84	C

Note: BW - black walnut, PA - paulownia, RO - red oak, WA - white ash,
WO - white oak, WP - white pine, YP - yellow poplar
*cells 7 and 8 planted in April 96, the rest planted in March 1997

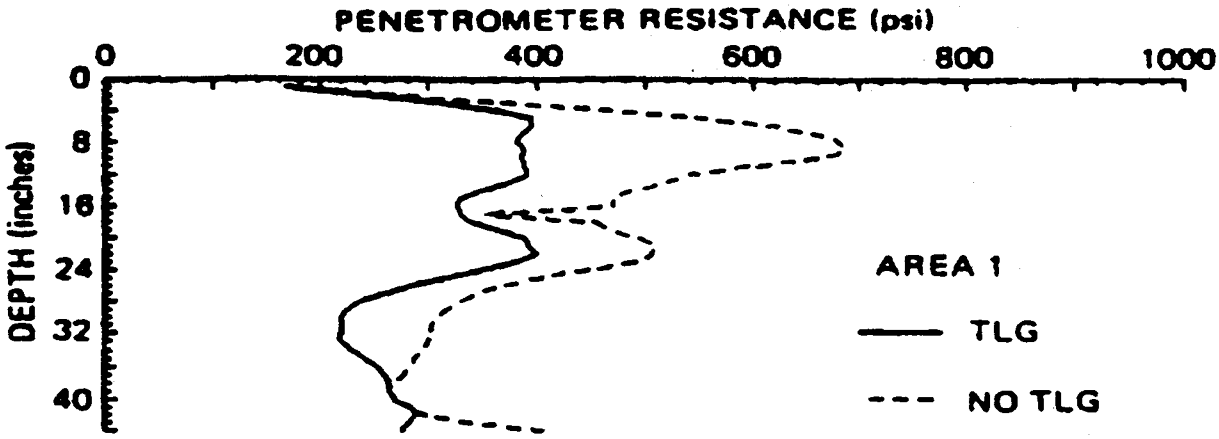

Figure 1. Typical penetrometer resistance profile for prime farmland soil (similar to Hooks and Jansen, 1986).

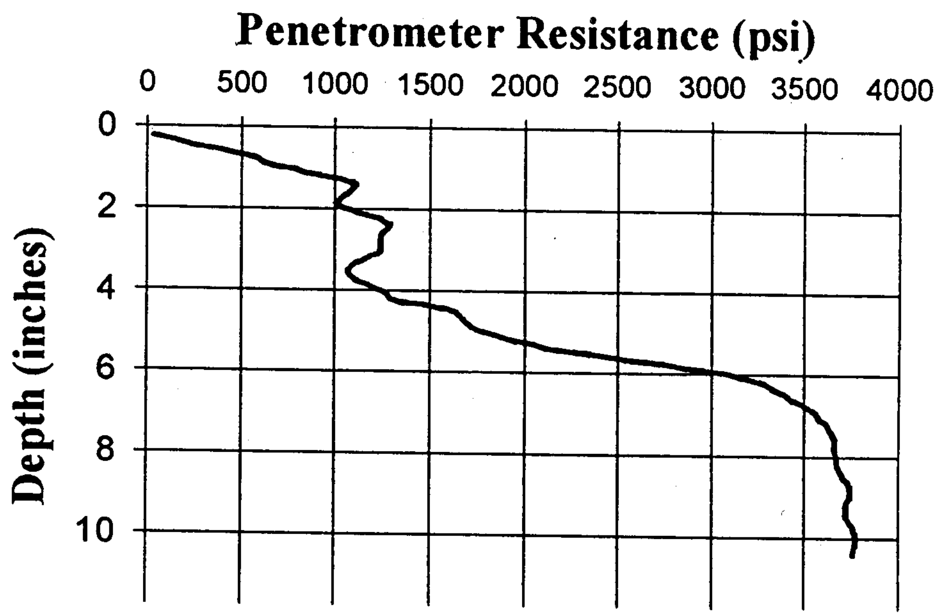

Figure 2. Typical penetrometer resistance profile for spoil material at the Star Fire Mine.

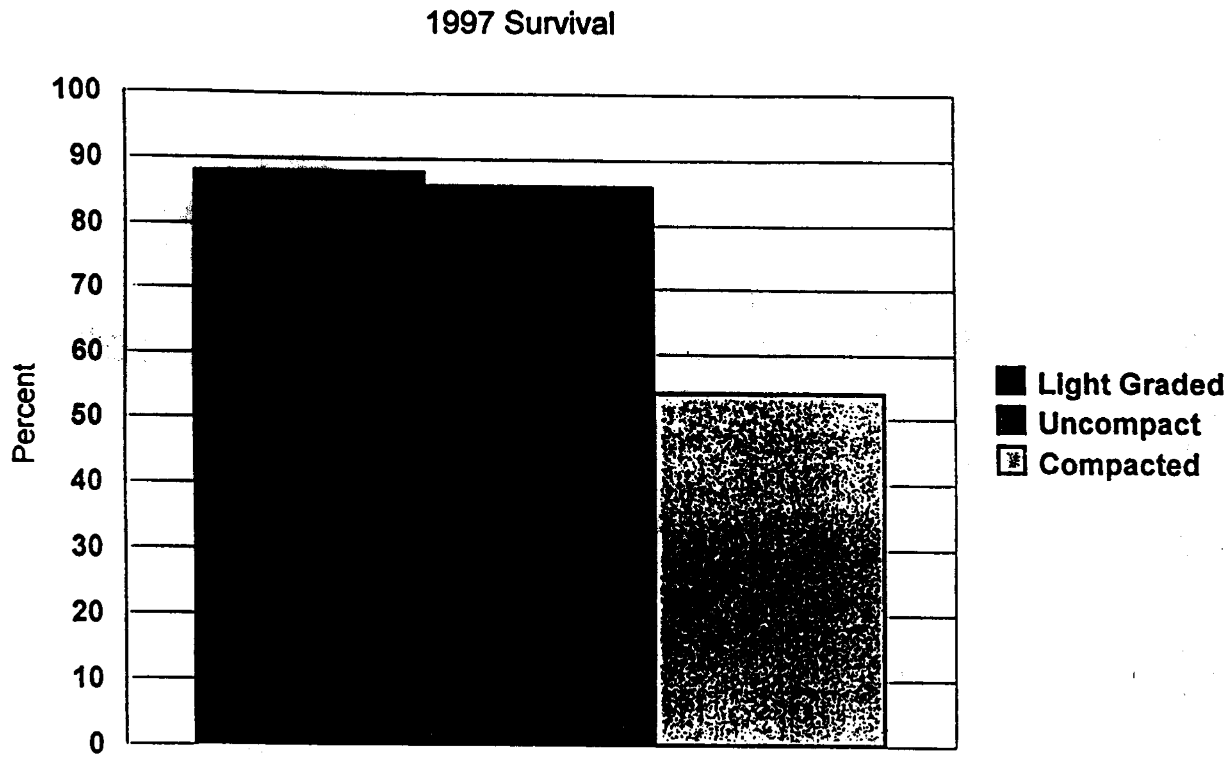

Figure 3. 1997 tree survival rate at the Star Fire Mine as a function of surface condition.

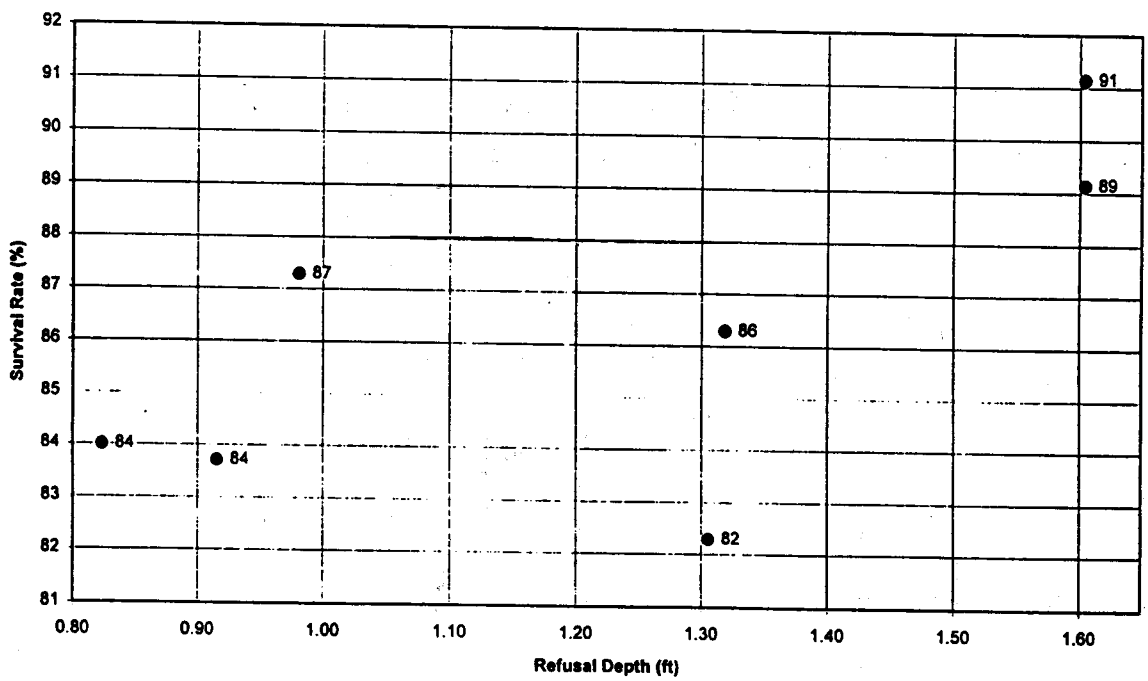

Figure 4. 1997 tree survival rate at the Star Fire Mine as a function of refusal depth.

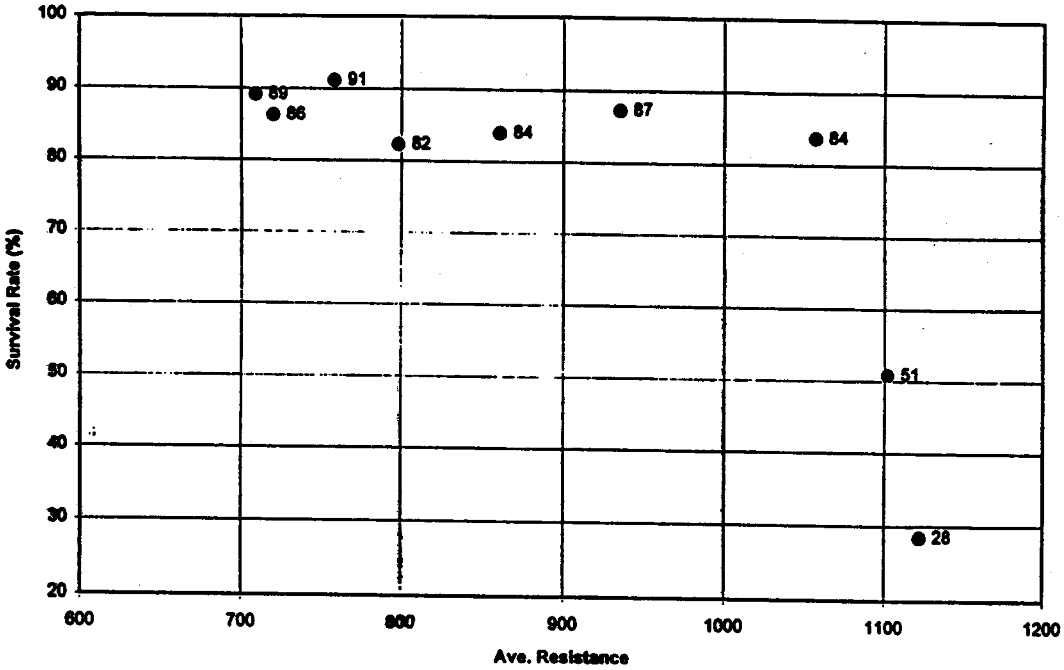

Figure 5. 1997 tree survival rate at the Star Fire Mine as a function of average penetration resistance.

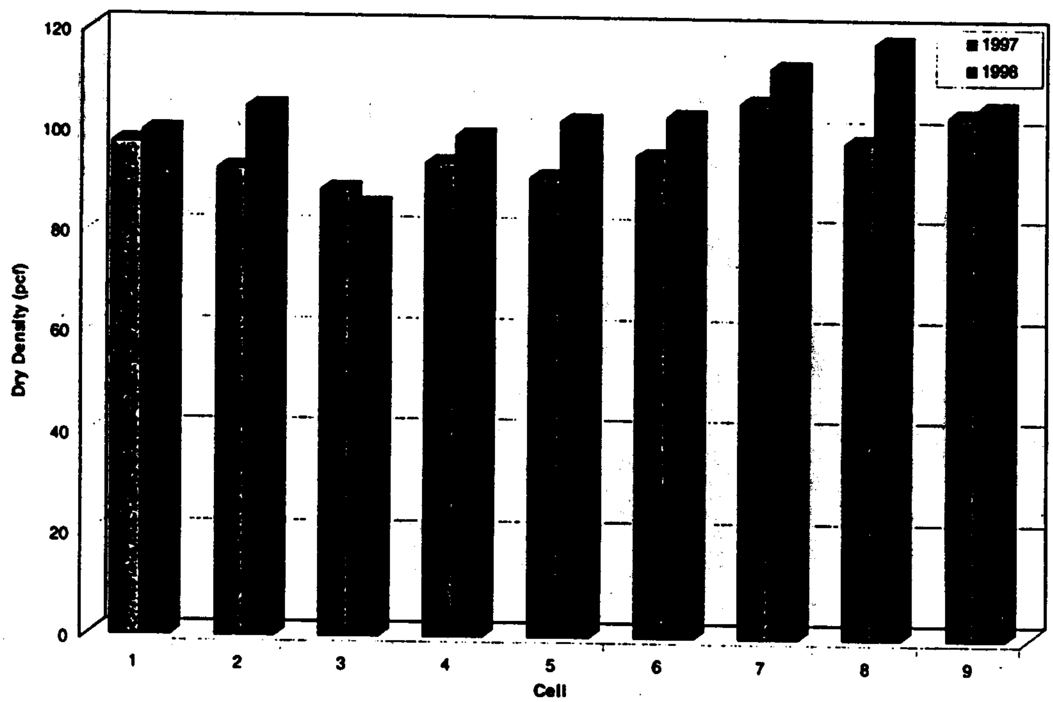

Figure 6. Two-year dry bulk density comparisons.

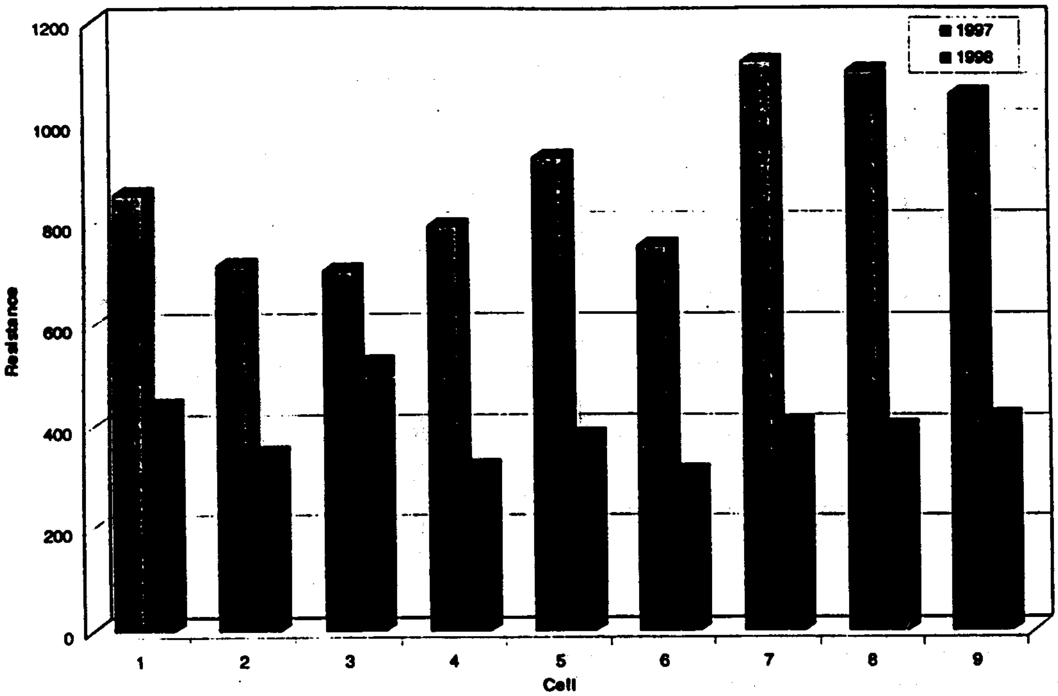

Figure 7. Two-year average penetration resistance comparisons.

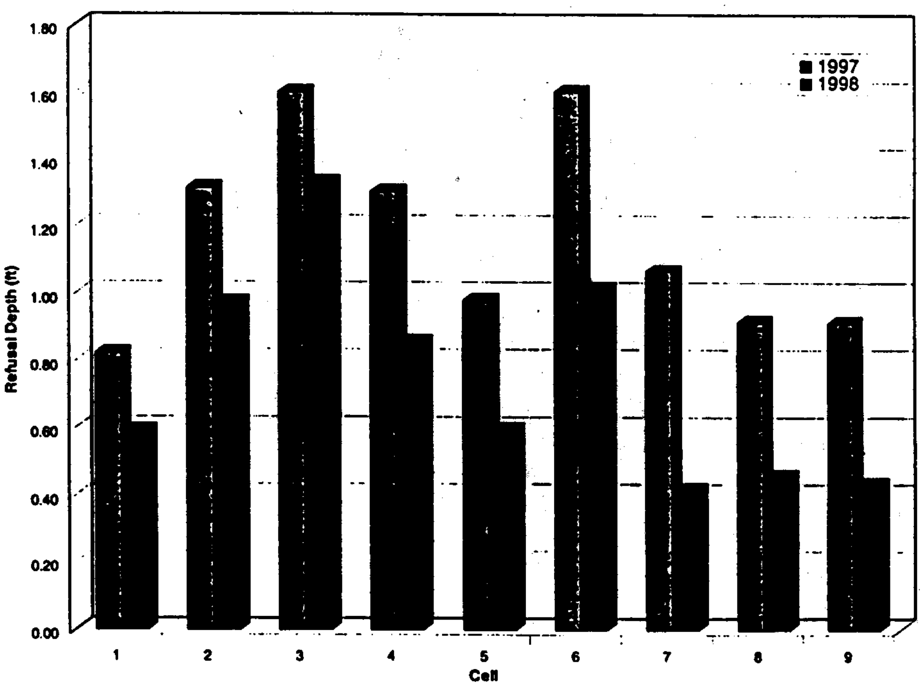

Figure 8. Two-year refusal depth comparisons.

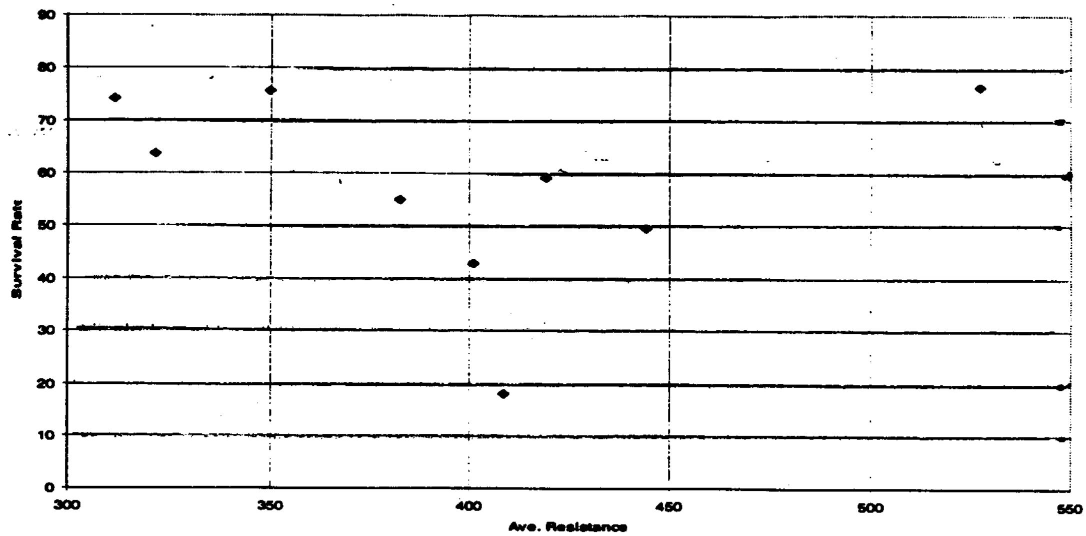

Figure 9. 1998 tree survival rate at the Star Fire Mine as a function of average penetration resistance.