Reforestation of Mined Land in the Northeastern and North-Central U.S.[1]

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ABSTRACT. This paper reviews the state of the art of surface mine reclamation for forestry in Pennsylvania, Maryland, West Virginia, Ohio, Indiana, and Illinois. Legislative constraints, socioeconomic issues, factors limiting the success of reforestation efforts, post-mining land-use trends, species options, and establishment techniques are discussed. Sources of assistance to landowners or managers are given and major publications on reclamation methods are cited. Information provided in the paper also applies to coal mining states adjacent to those listed above.

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Early reclamation efforts in the northern coal states commonly consisted of planting trees. Many of those sites planted to native conifers and hardwoods, and a few introduced species, today support excellent stands of timber (Kolar and Ashby 1978, Vogel 1979, Davidson 1981). However, as legislation requiring extensive grading and the rapid establishment of a vegetative cover became more prevalent, tree planting as a reclamation alternative rapidly diminished. Instead, the use of grasses and legumes, with hay/pasture as the post-mining land use, prevailed.

Thus, much of the change in the state of the art of revegetating mined land during the past few decades has resulted from changes in laws. Such changes, usually the result of sociopolitical pressures, have resulted in abrupt changes not only in reclamation practices but also in the direction of research. Research has generally been aimed at achieving the optimum system of revegetation within the constraints imposed by the existing laws.

Before 1977, the individual states had complete control over mining and reclamation within their boundaries. That changed with the passage of the Surface Mining Control and Reclamation Act of 1977 (Public Law 95-87). The states now regulate mining and reclamation within their boundaries only if they have laws at least as stringent and comprehensive as the federal law. This has served to lessen the differences in reclamation practices from state to state. Nevertheless, practices still differ from one part of a region to another because of differences in climate, soils, and type of overburden. Important provisions of PL 95-87 are:

1. Explicit preoperational plans must be developed for both the mining and reclamation operations.
2. Adverse environmental conditions must be avoided or ameliorated, and off-site pollution must be controlled.
3. A diverse and permanent vegetative cover must be rapidly achieved.

REFORESTATION

Forestry as a post-mining land use is recognized by PL 95-87 as viable and desirable. Regulations under this law, which were basically designed for agricultural land uses, seem overly stringent for forest areas (Ashby 1982). The regulations further define the success of a forest planting by the survival rate. Although forest plantings are successfully meeting these survival requirements, their potential for long-term growth has not been determined

[1] Editor's Note: This paper was written on request, in July 1983, from the committee organizing this journal. In my opinion the authors' responsiveness sets a high standard for such reviews in future issues of the *NJAF*.

and is not addressed by the regulations.

In addition to tree planting, the mined land must be graded, topsoil replaced, and a dense herbaceous ground cover established. Two of these practices are definitely detrimental to the establishment and subsequent growth of planted trees.

The detrimental effects of compaction as a result of grading were identified by Limstrom (1952) in the early 1950s and reaffirmed by Chapman in 1967 but are ignored in existing regulations. Present laws that require grading to approximate the original contour and topsoil replacement still create soil compaction problems associated with the grading (Kolar et al. 1981, Bussler et al. 1983).

Although a dense herbaceous cover is essential to control erosion, it presents a formidable obstacle to the establishment of tree seedlings. The value of controlling herbaceous ground cover for the establishment of hardwoods has long been recognized in the forest industry (Erdman 1967, von Althen 1971, Bey et al. 1976).

The replacement of topsoil has had a positive effect on the survival of some tree species on some areas (Kolar et al. 1981). However, in some situations, especially where compacted, topsoil replacement may adversely affect tree survival. Whether topsoil will have a positive or negative effect on tree growth has not been determined. Early indications are that root growth is restricted by the graded and compacted cast overburden (Spaniol 1982).

LIMITING FACTORS

Before laws were passed requiring the differential placement of overburden and the stockpiling and respreading of soil, tree establishment was limited mostly by adverse physical and chemical properties of the spoil banks. Steep slopes, an especially serious problem in West Virginia, resulted in both erosion and landslides. Extremely coarse-textured spoils created problems with the availability of water and nutrients. Dark-colored spoils often had excessively high surface temperatures. In the Midwest, where spoils often weathered rapidly into fine-textured material, plant establishment was sometimes limited by compaction from the regrading operation. Wherever pyritic materials are present their oxidation may create highly acidic conditions. These in turn often result in phytotoxic levels of exchangeable aluminum, manganese, and possibly other metals.

Current laws, with their requirements for regrading to approximate original contour, controlling surface runoff, differential overburden placement, stockpiling and respreading of soil, liming, fertilizing, and mulching, have reduced the seriousness of these problems. Nevertheless, problems still exist. Many of the sites currently being mined are ridges with steep slopes and shallow, infertile, coarse-textured soils. Liming, fertilizing, and mulching provide only temporary aid. And heavy equipment used in regrading and resoiling can cause serious compaction.

Furthermore, many old surface mines are being remined because improved technology and higher prices for coal make it economical to remove more overburden. On such sites, topsoil is insufficient, and the "best available" spoil material is often poor in quality.

On good planting sites currently being reclaimed, biotic rather than physical and chemical factors may be most limiting to plant establishment. Foremost among these is the previously mentioned interference from grasses and other herbaceous species. The cover provides excellent habitat for small rodents, which often feed on the tree seedlings. Larger animals, such as deer in Pennsylvania, browse and effectively limit the development of certain tree species. Type of herbaceous cover can influence deer browsing. Wheeler (1976) reported browse damage on forest trees only where legumes had been seeded. Disease organisms and insects may become more serious on grass-covered areas than on bare areas. Populations of some disease and insect species build up slowly over time and may not become a problem until several years after planting. Unfortunately, most species recommendations have been based on short-term studies.

Table 1. Costs (U.S. dollars) for tree planting in Indiana using three different methods of applying herbicides.

Cost item	Hand application[a] Cost/seedling	Hand application[a] Cost/acre	Planter application[b] Cost/seedling	Planter application[b] Cost/acre	Tractor application[c] Cost/seedling	Tractor application[c] Cost/acre
Seedling	0.06	53.40	0.06	52.20	0.06	52 20
Planting	0.20	178.00	0.30	261.00	0.20	174 00
Chemical	0.008	7.50	0.018	15.80	0.019	16 50
Application	0.18	160.20			0.04	38 50
	0.448	399.10	0.378	329.00	0.319	281 20

[a] Costs based on using 7′ × 7′ spacing (890 trees/acre)
[b] Costs based on using a sprayer mounted on tree-planting machine and a 5′ × 10′ spacing (870) trees/acre)
[c] Costs based on using a sprayer mounted on a tractor and a 5′ × 10′ spacing

CHOICE OF SPECIES

Vogel (1981) recommended 34 tree species for use on coal minesoils in the East; an additional 26 have more limited potential. However, not all were recommended for planting throughout the region. Many, such as loblolly and shortleaf pine, are climatically unsuited for the northern part of the region or for the higher elevations of West Virginia. Others, such as black walnut and yellow-poplar, are not well adapted to the infertile, droughty minesoils commonly found in many areas. Some species, such as European white birch and black locust, become more and more vulnerable to insect attacks as the stand ages and are unlikely to produce tree crops other than fuel wood. In fact, there is a growing belief that site improvement should be the primary objective for many strip-mined areas with production of merchantable crops a secondary objective. Because of the large number of limiting factors, only a handful of species (red pine, Japanese larch, red oak, and hybrid poplar) are capable of achieving sawlog size within a reasonable time on a majority of mine sites in Pennsylvania. On better sites and southward into West Virginia, southern Illinois, and southern Indiana, the list of such species grows Most mined sites in the Midwest seem capable of growing quality trees of valuable hardwood species such as black walnut, red oak, and yellow-poplar, if spoil compaction and herbaceous competition problems are overcome.

The quest for well-suited species continues because early studies were conducted under conditions different from those of today. Especially important is the identification of compatible mixes of trees and herbaceous plants Tall fescue, also called reed fescue, has been identified as a species that inhibits the growth of some woody species (Walter and Gilmore 1976, Todhunter and Beineke 1979), and therefore is not recommended for areas designated for tree planting. The ground cover species selected should also be susceptible to the chemicals used for weed control. Alfalfa has been found to be one of the more difficult species to control through the use of chemicals. Tree species that exhibit rapid early growth, such as black locust and European alder, and typical old-field species such as red pine and Virginia pine, seem better able to withstand competition from grasses and herbs.

Legumes and certain other species are especially useful because of their ability to fix atmospheric nitrogen. Thus species such as black locust and European alder are often used, not for their potential to produce merchantable crops, but for their value to improve the site and increase growth of associated species. Autumn olive, also a nitrogen-fixer, provides excellent food and cover for wildlife, but has the potential to become a pest by colonizing adjacent areas. Its use should be limited to areas where wildlife habitat is the primary land-use objective. The rapid juvenile growth of black locust can be a disadvantage because it often overtops and suppresses the more valuable associated species. Reducing the proportion of black locust in the planting plan to 25% or less helps to alleviate this disadvantage.

The search for well-suited plant materials does not stop at the species level. Many studies are underway to identify superior ecotypes or cultivars within a species. For example, Davidson (1977) working with ponderosa pine in Pennsylvania, and Funk (1973) working with European alder in the Midwest found that some seed sources were superior to others for planting on mined lands. Keys et al. (1980) reported significant differences in performance of Austrian pine from 12 seed sources planted on mined lands in West Virginia and Pennsylvania. Hybrids have also shown potential for reforestation of mined lands. Davidson and Vogel (1983) identified several clones of hybrid poplar that have performed well in Pennsylvania, Maryland, West Virginia, Kentucky, and Ohio. Current research with other hybrids such as pitch × loblolly pine may soon add additional plant materials that can be used successfully in mined-land reforestation.

TREE ESTABLISHMENT

Measures required to control pollution or to establish an herbaceous cover, such as regrading to approximate original contour, establishing water diversions, resoiling, ripping and harrowing, liming and fertilizing, and mulching also tend to favor the establishment of tree seedlings. Exceptions occur where the regrading results in compaction or where the site is overfertilized, a problem especially apparent on sites treated with municipal wastes. Although currently being used only on a small scale, application of municipal wastes is becoming more and more common in the populous Northeast and will probably require the development of special techniques to permit the establishment of trees.

Interference from an herbaceous cover is often a serious problem even on a conventionally treated site. The problem can be reduced if the tree seedlings are planted at the same time the herbaceous seed is sown. However, this is not always possible because the sites must be seeded through the growing season, whereas tree seedlings are usually planted only in the spring. Also, touch-up treatments to establish cover on failed spots can destroy established tree seedlings.

The problem of herbaceous interference can be avoided if unseeded strips are left on the contour in which the tree seedlings are later planted. Within a year or two, the herbaceous cover will invade and completely cover the unseeded strips, but by that time the tree seedlings should be much more competitive. However, special approval is needed from the regulatory agency to use this technique, and most agencies are reluctant to grant approval. In an already established dense herbaceous cover, control measures usually are necessary to ensure establishment of tree seedlings. Herbaceous cover can be controlled by either mechanical or chemical methods.

Because mechanical methods require more frequent applications, chemical control is more economical and more commonly used. Dowpon M with Amizine or Roundup with Princep 80 W are chemical combinations commonly used to attain pre- and post-emergence control. (Mention of commercial names does not indicate endorsement.) There are numerous other chemicals that could also be used. The chemicals are most often applied as a spray either by hand or by mechanical methods. With hand spraying, a circle of chemical is applied around each seeding. Hand spraying lacks the precision of mechanical application in applying the correct amount of chemical, but is more flexible over a wide range of ground and topographic conditions. Herbicides can be applied mechanically with a boom sprayer, either before or at the time of planting. Spray nozzles or herbicide wipers can be mounted on tree planting machines. Although mechanical application of herbicides is limited to areas suitable for agricultural equipment, it offers distinct advantages in the precision and cost of application.

Control of herbaceous competition is necessary to enhance seedling survival and may be required for 1 or 2 years to maintain survival rates. In addition, weed control for a number of years following establishment will maximize growth (Krajicek and Williams 1971, Bey and Williams 1976).

Tree planting is done mechanically or by hand. Hand planting is highly labor intensive. Although mechanical planting requires less labor, capital investment and maintenance costs are relatively high. Most seedlings are nursery-grown bare-root stock, but containerized seedlings are drawing considerable attention. Containerized seedlings allow the operator to extend the planting season and use less experienced planters because planting methods are less critical. However, containerized stock is often less robust than the older seedlings grown in conventional nurseries. Seedling quality and seedling care before and during planting therefore are important factors in successful seedling establishment.

Genetically superior planting stock is available from some nurseries. Although somewhat more costly, its better survival and growth may be crucial on adverse sites or in dense cover. Another potentially valuable modification is the use of seedlings inoculated with the proper mycorrhizal fungus. Considerable research has been done on this subject, and inoculated seedlings should soon be available commercially.

Because planting either containerized or bare-root seedlings in compacted soils often produces abnormal root systems, direct seeding is again receiving attention. This method seems more likely to succeed in the southern part of the region. In the northern part, the resulting seedlings are usually not well enough established to survive harsh winters or severe grass competition. A possible exception is black locust, with its rapid growth even in the first year

Mixtures of tree species have been used since the earliest strip-mine plantings. The mixtures are becoming more sophisticated, however. Instead of groups or strips, the more progressive operators are planting random mixtures. This is especially true where nitrogen-fixing species are used as nurse trees.

The cost of establishing trees in Indiana is summarized in Table 1. These are the costs incurred for contracting all phases of the work. The totals reflect only one herbicide application. Examination of the different costs reveals the economic advantages of mechanization. Hensley (1983) reported hand-planting costs in West Virginia of $226 to $450 per acre using 1,000 trees per acre at $76/M seedlings. This does not include control of herbaceous cover.

LAND–USE TRENDS

In Illinois, Reising (1982) noted that 44% of the acreage where surface coal mining was permitted was forest, whereas only 21% of the acreage would be forest when mining was completed. This is an accelerating trend, as mine operators recognize the additional reclamation costs associated with reforestation, and land managers demand that more land be reclaimed for agricultural uses. Once the mine operator has borne the cost of grading, topsoiling, and establishing ground cover, he has reclaimed the land to the standards required for bond release with the hay/pasture land use. Therefore, to carry the process one step further and establish trees is an additional cost. In addition, hay/pasture is a traditional income-producing land use in the Midwest, and therefore preferred. Few land managers recognize reforestation as economically viable for long-term management, and many forest plantings on land reclaimed to agricultural standards are planned for conversion to hay/pasture as soon as the reclamation bond is released. The mine operators, recognizing these circumstances, are pursuing means of limiting the forest land use to those areas unsuitable for agriculture, which in the Midwest under the prevailing regulations is a small portion of the land disturbed by surface mining.

To reverse the trend of losing forest acreage in the surface mining process, incentive and flexibility within the regulations are required (Reising 1982). In Illinois, a project in process will

Fig. 1. Three scenes (1965, 1971, and 1983) of a Kentucky site used to demonstrate reclamation. The site was mined for coal in 1959 and again in 1963. Scene 1 is after grading and installing a drainage system but before planting herbaceous and woody vegetation, in 1966. Scenes 2 and 3 show the same area after 6 and 18 growing seasons.

reclaim an area as forest by using minimal grading (Parr 1982). The area will be graded only to the extent necessary to replace and hold topsoil (30% slopes). This will provide a hill and valley topography. Once topsoil has been replaced, the ground cover and tree seedlings will be established by using normal procedures. This approach to reforestation will provide the necessary incentive for the operator to pursue forest as a post-mining land use because the cost of grading will be significantly reduced. Also, it is assumed that compaction may be lessened, creating a better-quality site for the survival and growth of newly established tree seedlings. The minimally graded area will not be topographically suitable for cultivated crops. Therefore, if successful, minimal grading could have a very positive impact on the forest resources being produced on surface-mined land.

APPLICATIONS

Land managers faced with the task of reforesting an area disturbed by surface mining have an abundance of assistance available to them. Information and guidance are available from numerous state and federal agencies. Many private consultants and reclamation contractors are in business to provide reclamation services.

In many instances, either PL 95-87 or state statutes will dictate the procedures, species mixtures, and applications to achieve reclamation on new disturbed areas. If the land manager wishes to deviate from established requirements, he will have to apply for a variance from the regulatory agencies. If the variance is to change land-use categories, he will have to show a higher land use and specify how this will be accomplished. Again, private consultants are available. The federal Office of Surface Mining and state departments of mining, natural resources, or environment can also provide assistance in preparing the application for variance. In some cases, the land manager may wish to attempt innovative or untested reclamation techniques. This is allowed provided an "experimental practices" application is completed and approved.

Assistance in developing reclamation plans for areas disturbed by surface mining of commodities other than coal, or for orphan mined land that has not been reclaimed, is available from local soil conservation districts, U.S. Soil Conservation Service offices, state universities, or state natural resources or environmental agencies Many states have reclamation guides that outline reclamation techniques and list recommended reclamation species.

Other sources of information in-

clude "A Guide for Revegetating Coal Minesoils in Eastern United States" (Vogel 1981). A recent symposium on abandoned mine reclamation addresses many of the problems associated with reforestation (Smeck and Sutton 1982). Also, proceedings of the trees for reclamation symposium (U.S. Dep. Agric. 1980) contains 30 papers on reclamation.

In conclusion, research and experience over the years (Fig. 1) have shown that most surface-mined areas can be forested if the correct procedures are followed. Problems such as compaction and excessive herbaceous competition are not insurmountable. Research and testing is continuing to improve establishment and management techniques to make forestry a preferred and cost-effective reclamation option.

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