United States
Department of
Agriculture

Forest Service

**Northeastern
Research Station**

General Technical
Report NE-262

Bibliography of Surface-Mine Reclamation Research: 1976-1993

Abstract

Contains citations for 177 articles and publications that describe research on or related to the reclamation of surface-mined lands conducted from 1976 through 1993 by scientists with the Northeastern Research Station and cooperating organizations. A subject index is included.

The Compiler

JERRY T. CREWS is a soil scientist with the Northeastern Research Station's Timber and Watershed Laboratory at Parsons, West Virginia.

Manuscript received for publication 1 November 1996

Published by:

USDA FOREST SERVICE
5 RADNOR CORP CTR SUITE 200
RADNOR PA 19087-4585

June 1999

For additional copies:

USDA Forest Service
Publications Distribution
359 Main Road
Delaware, OH 43015
Fax: (740)368-0152

Visit our homepage at: **http://www.fs.fed.us/ne**

Bibliography of Surface-Mine Reclamation Research: 1976-1993

Compiled by
Jerry T. Crews

Foreword

The following references to research on surface-mine reclamation published from 1976 through 1993 are arranged alphabetically by senior author. A subject index and an index of publications by author are included. This bibliography represents an update of "Annotated Bibliography on the Ecology and Reclamation of Drastically Disturbed Areas," General Technical Report NE-21, published by the Northeastern Forest Experiment Station in 1976.

1. Allaire, Pierre N. 1978. **New potential for some North American birds.** American Birds. 32(1): 3-5.

Describes how new mining and reclamation techniques are changing the avifauna of Appalachia.

2. Ashby, W. C.; Vogel, Willis G. 1993. **Tree planting on mined lands in the Midwest: a handbook**. Carbondale, IL; Southern Illinois University, Coal Research Center. 115 p.

The procedures used in the successful reclamation of surface-mined lands are discussed. Also included are sections on site preparation and management, types of plants used in reclamation programs, plant materials and handling, planting practices, species recommendations, and suggestions on land use.

3. Ashby, W. C.; Vogel, W. G.; Kolar, C. A.; Philo, G. R. 1984. **Productivity of stony soils on strip mines**. In: Erosion and productivity of soils containing rock fragments: proceedings of a symposium; 1982 November 28-December 3; Anaheim, CA. SSSA Spec. Publ. 13. Madison, WI: Soil Science Society of America: 31-44.

Surface mining traditionally mixed surface soils with underlying geologic materials that included rock fragments of various kinds and sizes. There is evidence that minesoils with coarse fragments may have productivity equal to or greater than premining soils. Coarse fragments can increase water entry and availability, porosity, aeration, and nutrient levels in uncompacted minesoils compared with many unlined soils. Understanding the beneficial as well as limiting effects of stones and coarse fragments in minesoils would be an important step toward better utilization of overburden resources following the extraction of coal.

4. Ashby, W. Clark; Davidson, Walter H.; Vogel, Willis G. 1989. **Soil pH guidelines for reclamation tree plantings**. In: Healthy forests, healthy world: proceedings of the 1988 Society of American Foresters national convention; 1988 October 16-19; Rochester, NY. SAF Publ. 88-01. Bethesda, MD: Society of American Foresters: 210-213.

Twenty-four species of forest trees up to 32 years old were grown on eastern/midwestern minesoils with a range in surface soil pH of less than 3 (extremely acid) to 8+ (moderately alkaline). Statistical correlations of d.b.h., height, and/or survival of the different species with soil pH were established. Types of responses in the midwestern studies with increasing pH above 4.5 were greater growth and/or survival (black walnut), lesser growth (red maple and all pine species), and little effect (sweetgum). In the eastern studies with greater soil acidity, only two birch species had decreased d.b.h. with increasing pH above 3.1. Few tree species survived below pH 3.

5. Ashby, W. Clark; Vogel, Willis G.; Kolar, Clay A. 1983. **Use of nitrogen-fixing trees and shrubs in reclamation**. In: Pope, P.E., ed. Better reclamation with trees: proceedings of the 3rd annual conference; 1983 June 2-3; Terre Haute, IN. West Lafayette, IN: Purdue University, Department of Forestry and Natural Resources: 110-11.

6. Ashby, W. Clark; Vogel, Willis G.; Rogers, Nelson F. 1985. **Black locust in the reclamation equation**. Gen. Tech. Rep. NE-105. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 12 p.

Black locust has been planted and seeded more than any other tree species on lands surface mined for coal in the Eastern United States. Black locust provides quick cover for stabilization and esthetics; supplies nitrogen and nutrient-rich litter to soil; improves the site for establishment of other higher quality trees; grows in a wide range of minesoil conditions, including extremely acid soils; grows better than most trees in soils compacted by grading and topsoiling practices; can be established by seeding; and is useful for posts, fuel, and biomass production. Conversely, black locust may overtop and damage companion trees and be susceptible to damage by the locust borer. Also, it spreads to adjacent open areas by root suckers and seed, its thorns are hazardous to people and equipment, and seeded stands may be nearly impenetrable to about 6 to 8 years of age.

7. Baker, C. Jacyn; Melhuish, John H., Jr. 1984. **Separation of unsaturated fungal fatty acid methylesters by reversed phase liquid chromatography for further evaluation by gas chromatography**. Journal of Chromatography. 284: 251-256.

The combined use of HPLC and GLC for the analysis of complex mixtures of fatty acids of biological origin is a powerful and convenient tool.

8. Baker, C. Jacyn; Tomerlin, J. Robert; Mock, Norton; Davidson, Lynn; Melhuish, John. 1987. **Effects of cations on germination of urediniospores of *Uromyces phaseoli***. Phytopathology. 77: 1556-1560.

Urediniospores of *Uromyces phaseoli* races 39 and 40 germinated better in unpurified tap water than in ultrapure laboratory water. Experiments with freeze-dried residue of tap water dissolved in ultrapure water suggested that the water contained a component that stimulated spore germination. When ions were removed from the water with ion-exchange resins, only cation-exchange resins decreased spore germination. The major inorganic cations present were Ca^{2+}, K^{+}, Mg^{2+}, and Na^{+}. Spores of both races were incubated for 3 to 4 hours with solutions containing varying amounts of these cations. Germination was measured with a microscope to view 100 spores for each of five replicates. At concentrations between 0.1 and 3 mM, Ca had a stipulatory effect proportional to the amount of cation present. Concentrations greater than 3 mM had little or no additional effect on germination. Spore germination in the presence of Ca^{2+} was comparable to that of tap water; Mg had a lesser effect on spores.

9. Becker, Charles W.; Woods, Frank W.; Curtis, Willie. 1986. **Water quality of mined and unmined watersheds in east Tennessee**. Journal of the Tennessee Academy of Science. 61(4): 98-104.

In late 1980 and early 1981, monitoring stations were installed in three small watersheds in the Cumberland Mountains and three in the Cumberland Plateau of east Tennessee to evaluate the effects of surface mining on water quality. Each set had a recently mined, old mined, and unmined watershed. There was a relationship between seasonal variations in water quality and flow rates, and there were significant differences in water quality between mined and unmined watersheds. Mined watersheds generally had higher levels of minerals and greater turbidity.

10. Beckjord, P. R.; Melhuish, J. H., Jr. 1984. **Effects of various concentrations of *IBA* on the propagation of stem cuttings of *Paulownia tomentosa***. Publ. ESB 2. College Park, MD: University of Maryland, Agricultural Experiment Station. 4 p.

Stem sections of *Paulownia tomentosa* with and without nodes were taken from dormant l-year-old Paulownia sprouts and propagated using several concentrations of IBA. Fresh root weight increased as IBA concentration increased, but survival of cuttings was similar for many treatments. The average number of shoots per living cutting was the same for many treatments, but the location of the initiation of new roots from the stem section varied considerably among treatments, as did fresh root weight. Stem cuttings treated with 8,000 ppm IBA provided acceptable quantity and quality of rooted cuttings.

11. Beckjord, P. R.; Melhuish, J. H., Jr.; Griffiths, L. A. 1984. **Nursery production trials of *Paulownia tomentosa* seedlings**. Publ. ESB 3. College Park, MD: University of Maryland, Agricultural Experiment Station. 5 p.

Before sowing on a prepared nursery bed, Paulownia seeds were soaked with water or not soaked, mixed with a water absorbing material or not mixed, and mixed with dry sawdust. Part of the nursery bed was covered with shade cloth. Seedling density (number of seedlings per square foot) was measured 45, 65, and 125 days after planting. Maximum density (10.4 seedlings/ft^2) was obtained when dry seeds received no treatment other than covering with a shade cloth. Density in all other treatments ranged from 0.1 to 4.3 seedlings/ft^2, well below a satisfactory number of 6 to 8 seedlings/ft^2 for nursery production of Paulownia seedlings.

12. Beckjord, P. R.; Melhuish, J. H., Jr.; Kundt, J. F. 1985. **Survival and growth of paulownia seedlings are enhanced through weed control**. Journal of Environmental Horticulture. 3(3): 115-117.

Four treatments of preemergence herbicide and a water control were compared in circular plots around cut-off stumps of l-year-old, field-grown *Paulownia tomentosa* seedlings. Tree survival and growth were significantly increased with the use of Princep (simazine) and Velpar (hexazinone) for weed control. Velpar significantly reduced weed cover compared to the other treatments.

13. Beckjord, P. R.; Melhuish, J. H., Jr.; McIntosh, M. 1985. **Influence of nitrogen and phosphorus fertilization on ectomycorrhizal formation of *Quercus alba* and *Q. rubra* seedlings by *Pisolithus tinctorius* and *Scleroderma auranteum***. In: Molina, Randy, ed. Proceedings, 6th North American conference on mycorrhizae; 1984 June 25-29; Bend, OR. Corvallis, OR: Oregon State University: 221.

The percentage of ectomycorrhizal short roots (PESR) on *Quercus alba* and *Q. rubra* inoculated with *Pisolithus tinctorius* followed a nearly matching pattern among fertilizer treatments, supporting the hypothesis that there may be an optimal amount of N or P for maximum mycorrhizal formation. Several cycles of low and high fertilizations could produce well-balanced seedlings with adequate growth and PESR for planting.

14. Beckjord, Peter R.; McIntosh, Marla S.; Hacskaylo, Edward; Melhuish, John H., Jr. 1984. **Inoculation of loblolly pine seedlings at planting with basidiospores of ectomycorrhizal fungi in chip form**. Res. Note NE-324. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 4 p.

Basidiospores of the ectomycorrhizae-forming fungi *Pisolithus tinctorius* and *Scleroderma auranteum* incorporated into an organic hydrocolloid can be used successfully in field inoculation. Containerized loblolly pine seedlings were inoculated during outplanting by this method. Results showed that basidiospore chips were effective inocula.

15. Beckjord, Peter R.; Melhuish, John H., Jr.; Crews, Jerry T.; Farr, David F. 1990. **Epigeous ectomycorrhizal fungi of oaks and pines in forests and on surface mines of western Maryland**. Tree Planters' Notes. 41(1): 15-23.

Epigeous basidiocarps of ectomycorrhizal fungi were collected for 2 years from oak forests, 1 year from conifer forests, and 1 year from oak and conifer reforested surface mines in western Maryland. Botanical, physiographic, and edaphic data were collected. A total of 291 specimens representing 18 genera and 33 identified species was obtained. The ecological implications for the occurrence of these fungi on these sites are discussed.

16. Beckjord, Peter R.; Melhuish, John H., Jr.; Hacskaylo, Edward. 1986. **Ectomycorrhiza formation on sawtooth oak by inoculation with basidiospore chips of *Pisolithus tinctorius* and *Scleroderma citrinum***. Journal of Environmental Horticulture. 4(4): 127-129.

Basidiospores of the ectomycorrhiza-forming fungi *Pisolithus tinctorius* and *Scleroderma citrinum* incorporated into an organic hydrocolloid and stored up to 5 years can be used successfully in inoculations. Container-grown sawtooth oak

seedlings were inoculated with basidiospores that were incorporated and stored in chips of compressed sand and peat moss. Basidiospore chips were manufactured each year after several collections of sporocarps from two locations and stored up to 5 years. Sufficient basidiospores remained viable in chip form for ectomycorrhiza formation of sawtooth oaks.

17. Beckjord, Peter R.; Melhuish, John H., Jr.; McIntosh, Marla S. 1985. **Effects of nitrogen and phosphorus fertilization on growth and formation of ectomycorrhizae of *Quercus alba* and *Q. rubra* seedlings by *Pisolithus tinctorius* and *Scleroderma auranteum***. Canadian Journal of Botany. 63(10): 1677-1680.

18. Beckjord, Peter R.; Melhuish, John H., Jr.; McIntosh, Marla S.; Hacskaylo, Edward. 1983. **Effects of nitrogen fertilization on growth and ectomycorrhizal formation of *Quercus alba*, *Q. rubra*, *Q. falcata*, and *Q. falcata* var pagodifolia**. Canadian Journal of Botany. 61(10): 2507-2514.

Quercus alba, *Q. rubra*, *Q. falcata*, and *Q. falcata* variety pagodifolia seedlings were grown for 105 or 110 days in containers in a greenhouse in a medium with and without vegetative or basidiospore inoculum of the ectomycorrhizal fungi *Pisolithus tinctorius* and *Scleroderma auranteum*. At 15 days after planting acorns, nitrogen (N) in the form of sodium nitrate or ammonium chloride was added to each container at the rates of 0.0 or 100 mg N per seedling. Growth of all *Quercus* seedlings that were not fertilized was significantly less than seedlings fertilized with nitrate or ammonium nitrogen (100 mg N). Ectomycorrhizal development of all *Quercus* seedlings that were not fertilized or fertilized with sodium nitrate (100 mg N) was significantly less than that of seedlings fertilized with ammonium chloride (100 mg N). Ectomycorrhizal development of oak species varied with different mycorrhizal inocula.

19. Bevenger, G. S.; Troendle, C. A. 1987. **The Coon Creek water yield augmentation pilot project**. In: Management of subalpine forests: building on 50 years of research: proceedings of a technical conference; 1987 July 6-9; Silver Creek, CO. Gen. Tech. Rep. RM-149. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 145-149.

Research in the Rocky Mountain subalpine zone has demonstrated that vegetative manipulation (primarily clearcutting) causes a net reduction in evapotranspirational losses, changes the aerodynamics and energy balance of the timber stand, and results in increased streamflow. Because the results of research on small watersheds has shown that water yield can be increased, and because forest management is one of several options for manipulating water yield, the Coon Creek Water Yield Augmentation Pilot Project was initiated to apply state-of-the-art technology in water-yield management on an operational timber sale.

20. Bowers, Lynne J.; Melhuish, John H., Jr. 1987. **Elemental analysis of red oak and loblolly pine growing near an inactive chromium smelter**. In: Hay, Ronald L.; Woods, Frank W.; DeSelm, Hal, eds. Proceedings of the 6th central hardwood forest conference; 1987 February 24-26; Knoxville, TN. Knoxville, TN: University of Tennessee: 231-245.

Twenty-four tree cores were collected from northern red oak and loblolly pine growing near an inactive chromium smelter north of Memphis, Tennessee. Elemental concentrations detected in the cores are comparable with literature reports for trees growing in areas affected by pollution. The results substantiate previous observations that metal accumulation rates vary with the growth rate within trees, among trees on the same site, and among species.

21. Bowers, Lynne J.; Melhuish, John H., Jr. 1988. **Comparison of elemental concentrations in the wood of three tree species growing adjacent to an inactive chromium smelter**. Bulletin of Environmental Contamination and Toxicology**.** 40: 457-461.

Studies of plant tissues have been conducted to determine the degree and spatial extent of point-source pollutants. Differences in accumulation rates among species have been used to identify plants that are good bioindicators of the status of specific elements in soils. Most of these studies have used herbaceous plants or leaves of woody plants. However, it is the woody tree bole that provides long-term storage of elements dispersed by anthropogenic sources of pollution.

22. Bowers, Lynne J.; Melhuish, John H., Jr. 1988. **Silicon content in wood and bark of baldcypress compared to loblolly pine and southern red oak**. Transactions of the Kentucky Academy of Science. 49(1-2): 1-7.

The durability and resistance to decay of baldcypress wood have been attributed to the quantity and type of extractives in the wood. Studies of agricultural plants have linked variations in silicon content with the degree of resistance to herbivory and fungal attack. Results show that baldcypress bark and wood contain higher concentrations of silicon than pine and oak. The durability of baldcypress wood as well as the ability of this species to tolerate long periods of flooded soil may be related to the higher silicon content.

23. Branson, Branley A.; Batch, Donald L.; Curtis, Willie R. 1984. **Small-stream recovery following surface mining in east-central Kentucky**. Transactions of the Kentucky Academy of Science. 49(1-2): 55-72.

Physiochemical piscine and macrobenthological data secured from two small-stream drainages affected by surface mining in eastern Kentucky are analyzed.

24. Bryan, B. A.; Hewlett, J. D. 1981. **Effect of surface mining on storm flow and peak flow from six small basins in eastern Kentucky**. Water Resources Bulletin. 17(2): 290-299.

Hydrologic records from six small watersheds in eastern Kentucky were analyzed to determine the effect of surface mining on stormflows and peakflows. Average stormflow volumes were not changed by surface mining, while average peakflows were increased by 36 percent. Peak flow increased only in the summer. Maximum annual stormflows, usually in winter or spring, were reduced slightly. No time trend in stormflows or peakflows was detected in 5 years of postmining records.

25. Carter, K. K.; DeHayes, D. H.; Demeritt, M. E., Jr.; Eckert, R. T.; Garrett, P. W.; Gerhold, J. E. Kuser, H. D.; Steiner, K. C. 1988. **Tree improvement in the Northeast: interim summary and recommendations for selected species**. Tech. Bull. 131. Orono, ME: University of Maine Agricultural Experiment Station. 50 p.

Provides an overview of our current understanding of genetic variation and tree-improvement practices for 11 common tree species in the Northeast.

26. Cech, Franklin C.; Keys, Roy N.; Davidson, Walter H. 1983. **Establishment and early growth of sweetgum planted on disturbed land**. In: Pope, P. E., ed. Better reclamation with trees: proceedings of the third annual conference; 1983 June 2-3; Terre Haute, IN. West Lafayette, IN: Purdue University, Department of Forestry and Natural Resources: 217-228.

Sweetgum seedlings from 34 seed sources representing the natural range of this species were planted on a forest site, a reclaimed deep-mine refuse pile, and a reclaimed surface mine. There were differences in height growth and survival among sources and sites. Northern sources grew fastest but were the shortest seedlings due to susceptibility to winter dieback. Growth and survival was best on the forest site. Poor growth and survival on the reclaimed refuse pile was attributed to low pH. Poor growth on the reclaimed surface mine was attributed to competition and possible allelopathic effects of the grass and herbaceous cover.

27. Chambers, Jeanne C.; MacMahon, James A.; Wade, Gary L. 1992. **Differences in successional processes among biomes: importance in obtaining and evaluating reclamation success**. In: Chambers, Jeanne C.; Wade, Gary L., eds. Evaluating reclamation success: the ecological consideration—proceedings of a symposium; 1990 April 23-26; Charleston, WV. Gen. Tech. Rep. NE-164. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 59-72.

28. Chambers, Jeanne C.; Wade, Gary L., eds. 1992. **Evaluating reclamation success: the ecological consideration—proceedings of a symposium**; 1990 April 23-26; Charleston, WV. Gen. Tech. Rep. NE-164. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 107 p.

Includes 10 papers from a symposium organized to review what is known about the ecological principles that will govern the ultimate success or failure of all reclamation efforts on drastically disturbed lands. The papers cover four general areas: soil biological properties and nutrient cycling; vegetation dynamics; animal recolonization; and landscape-scale processes.

29. Chambers, Jeanne C.; Wade, Gary L. 1992. **Evaluating reclamation success using ecological principles: a holistic approach**. In: Chambers, Jeanne C.; Wade, Gary L., eds. Evaluating reclamation success: the ecological consideration—proceedings of a symposium; 1990 April 23-26; Charleston, WV. Gen. Tech. Rep. NE-164. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 105-107.

30. Creek, Robert; Wade, Gary L. 1985. **Excretion of phenolic compounds from the roots of *Festuca arundinacea*, *Eragrostis curvula*, and *Lespedeza striata***. Transactions of the Kentucky Academy of Science. 46(1-2): 51-55.

Festuca arundinacea, *Eragrostic curvula*, and *Lespedeza striata* were grown hydroponically using a continuous circulating system in which root exudates were collected in columns containing XAD-4 resin. The exudates were separated into neutral, acidic, and basic fractions. Lettuce radicle bioassay showed that only the neutral fractions were inhibitory. Analysis of the neutral fractions by paper chromatography, TLC, and gas chromatography indicated the presence of five inhibitory phenolic compounds: cinnamic acid, ferulic acid, gallic acid, gentisic acid, and syringic acid.

31. Crews, Jerry T. 1984. **Effect of minesoil compaction on growth and yield of KY-31 tall fescue and sericea lespedeza**. Res. Note NE-320. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 5 p.

Kentucky 31 tall fescue and sericea lespedeza were sown on clay and loam minesoils that had been screened through a No. 10 sieve and compacted to densities of 1.6, 1.8, and 2.0 g/cm^{-3}. Stands of sericea lespedeza were more difficult to establish than fescue on both minesoils and were more susceptible than fescue to increased levels of compaction. Yields of dry matter averaged over all densities were greater on the clay than on the loam minesoil.

32. Crews, Jerry T.; Dyer, Kenneth L. 1984. **Evaluation of Bentonite for the control of acid drainage from surface mined lands**. In: Surface mining and water quality: fifth annual West Virginia surface mine drainage task force symposium; 1984 March 21-22, Morgantown, WV. Charleston, WV: West Virginia Mining and Reclamation Association: 1-9.

Bentonite is a montmorillonitic clay known for its water sealing action. When wet it expands to form a mass of crystalline sheets largely impenetrable by water. Bentonite is evaluated by developing a bentonite/minesoil seal over a layer of toxic minewaste underlaid by PVC plastic lining. In

addition to three control plots containing no bentonite, three plots contain 1 lb of bentonite/ft^2, and three plots contain 2 lb/ft^2. The plots are approximately 16 by 16 feet. Drains above and below the bentonite layer are connected to 55-gallon barrels. The volume of runoff is measured in the barrels.

33. Curtis, Willie R. 1977. **Sampling for water quality**. In: Kirchoff, William H., ed. Methods and standards for environmental measurement: proceedings of the 8th international IMR symposium; 1976 September 20-24, Gaithersburg, MD. Spec. Publ. 464. Washington, DC: U.S. Department of Commerce, Natural Bureau of Standards: 237-244.

To determine the frequency of sampling that provides the best estimate of water quality from the fewest samples, samples collected weekly from six first-order streams in eastern Kentucky over 7 water years were analyzed. Results indicate that baseline water quality can be adequately defined by sampling every 2 weeks for 1 year. Biweekly sampling also was adequate during and immediately after surface mining. Monthly sampling generally was adequate a year or more after mining was completed. Regression analyses indicated that specific conductance can be used to estimate the concentrations of dissolved solids and of dissociated ions such as calcium, magnesium, and sulfate.

34. Curtis, Willie R. 1977. **Surface mining and the flood of April 1977.** Res. Note NE-248. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 4 p.

Data from experimental sites in Breathitt County, Kentucky, and Raleigh County, West Virginia, showed that during a major rainstorm on April 4, 1977, peak streamflow from surface-mined watersheds was lower than that from adjacent or nearby unmined watersheds.

35. Curtis, Willie R. 1978. **Hydrologic aspects of surface mining in the East**. In: Proceedings of 1977 annual meeting of the Society of American Foresters; 1977 October 2-5; Albuquerque, NM. Bethesda, MD: Society of American Foresters: 152-157.

The hydrology of surface-mined land is compared to that of unmined forested land. Surface mining results in drastic land disturbance compared to timbering activities. Hydrology may be adversely affected due to mining activities. However, there is evidence that some changes may be desirable due to changes in potential detention and retention storage capacities.

36. Curtis, Willie R. 1978. **Mined-land reclamation**. In: Proceedings of 3rd national conference on the interagency energy/environmental research and development program; 1978 June 1-2; Washington, DC. Publ. EPA 600/9-78-022; Washington, DC: U.S. Environmental Protection Agency: 187-216.

Reclamation technology has made significant advances during the past 30 years. Using chemical, physical, and biological data, it is possible to move and place overburden materials in a manner that will enhance vegetation establishment and growth. Vegetation can be established on most surface-mine spoils when proper mining and planting techniques are used. A suitable seedbed is essential. Amendments must be used to provide nutrients, alleviate acidity, and improve moisture conditions. Mulches often mean the difference between good and poor vegetative cover. The proper time of seeding and planting often is just as important as species selection. Legislation generally determines the level of reclamation that is sought, though technology is not always available to meet regulatory requirements.

37. Curtis, Willie R. 1979. **Effects of surface mining on hydrology, erosion, and sedimentation in eastern Kentucky**. In: 4th Kentucky coal refuse disposal and utilization seminar; 1978 June 6-7; Pineville, KY. Lexington, KY: University of Kentucky, Institute for Mining and Minerals Research: 17-19.

Research by the USDA Forest Service at Berea, Kentucky, has shown that surface mining results in increases in storm peakflows during and immediately after mining, but that peaks may be significantly lower after reclamation is completed. Impoundments on surface mine lands can be effective in controlling runoff and erosion provided the ponds are constructed properly. Erosion and subsequent sedimentation are greatest during early stages of mining but diminish rapidly as the land is reclaimed and vegetation growth progresses.

38. Curtis, Willie R. 1979. **Successful revegetation of coal-mined lands in the United States**. In: Proceedings of the 2nd U.S.-Polish symposium on coal surface mining and power production in the face of environmental protection requirements; 1979 September 26-28; Castle Ksiaz, Poland. Publ. EPA 600/7-79-159. Washington, DC: U.S. Environmental Protection Agency: 207-220.

Trees were used almost exclusively in early efforts to vegetate surface-mine spoils. Around 1960, herbaceous species supplanted trees as greater emphasis was placed on erosion control. Today, research is directed toward simultaneous establishment of herbaceous tree species. Physical, chemical, and biological properties of mine spoils create numerous problems in vegetating them. Many of these problems can be overcome by seedbed preparation and the use of lime, fertilizer, and mulch on selected plant species. Several examples of successful revegetation are given.

39. Curtis, Willie R. 1979. **Surface mining and the hydrologic balance**. Mining Congress Journal. 35-40.

Data from experimental sites in Breathitt County, Kentucky, and Raleigh County, West Virginia, during major rainstorms on April 4, 1977, and December 8-10, 1978, showed that peak streamflow from surface-mined watersheds was lower than that from adjacent or nearby unlined watersheds.

40. Curtis, Willie R. 1980. **Planning surface mining activities for water control**. In: Youngberg, Chester T., ed. Proceedings of the 5th North American forest soils conference; 1978 August 6-10; Fort Collins, CO. Fort Collins, CO: Colorado State University: 366-375.

Planning surface-mining activities for water control requires an understanding of basic hydrologic processes. These include infiltration, soil water storage, surface storage, runoff, peakflow, water yield, groundwater, and water quality. Several techniques for controlling water on surface-mined areas are described.

41. Curtis, Willie R. 1982. **Reclamation research needs in relation to Public Law 95-87**. In: Land-use allocation: processes, people, politics, professionals: proceedings 1980 convention of the Society of American Foresters; 1980 October 6-8; Spokane, WA. Bethesda, MD: Society of American Foresters: 70-76.

Increasing demand for coal as an energy source in the United States has led to a dramatic increase in surface mining. It is essential for the nation's well being to consider the wise use and proper extraction of coal and other minerals so that other resources are neither wasted nor impaired. It is imperative to find new and better ways to mine and reclaim land for maximum mineral yield with minimum damage to other resources.

42. Curtis, Willie R. 1985. **Impoundments on mined mountaintops in eastern Kentucky**. In: Reclamation of lands disturbed by surface mining: a cornerstone for communication and understanding: 1984 national meeting of the American Society for Surface Mining and Reclamation; 1984 July 10-13; Owensboro, KY. Wilmington, DE: Science Reviews: 249-274.

Impoundments on surface-mined lands date to the beginning of surface mining and usually were unplanned. Such impoundments on contour-type mining sites often failed, contributing to slides and excessive stream sedimentation. In some states, legislation was planned to prohibit impoundments. In 1973, two impoundments were constructed and instrumented on a mountaintop mine in eastern Kentucky to study their effects on mined-land hydrology. Wells drilled in four directions from the ponds were used to track water-table development. Automatic recorders were used to obtain data on rainfall on and runoff from the drainage areas of the ponds. The relationship between water level in the ponds and water-table elevations in the wells is described.

43. Curtis, Willie R.; Dyer, Kenneth L.; Williams, George P., Jr. 1986. **A manual for training reclamation inspectors in the fundamentals of hydrology**. Ankeny, IA: Soil Conservation Society of America. 56 p.

This handbook is designed to help nonhydrologists achieve a basic understanding of hydrology as it relates to surface mining and reclamation. Surface coal-mining and reclamation inspectors will find it useful in implementing regulatory programs. The handbook includes clues and indicators of potential problems, ways to prevent or mitigate them, and observation and sampling techniques.

44. Curtis, Willie R.; Superfesky, Michael J. 1977. **Erosion of surface-mine spoils**. In: New directions in century three: strategies for land and water use. Proceedings of 32nd annual meeting of the Soil Conservation Society of America; 1977 August 7-10; Richmond, VA. Ankeny, IA: Soil Conservation Society of America: 154-158.

Erosion from head-of-hollow fill and from a site reclaimed to its original contour was studied. The effects of time, precipitation, and slope position were considered. Erosion on a back-to-contour slope totaled 32.93 mm over 20 months. Erosion from a head-of-hollow fill totaled 23.83 mm over 26 months. Long uninterrupted spoil slopes were conducive to the formation of rills and gullies.

45. Czapowskyj, Miroslaw M. 1976. **Annotated bibliography on the ecology and reclamation of drastically disturbed areas**. Gen. Tech. Rep. NE-21, Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 93 p.

Contains 591 annotated literature references, related primarily to mining effects and reclamation in the coal regions of the United States. Each reference is indexed by area, material, and general subject.

46. Czapowskyj, Miroslaw M. 1978. **Hybrid poplar on two anthracite coal-mine spoils: 10-year results**. Res. Note NE-267. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment station. 5 p.

Uprooted dormant cuttings of 28 hybrid poplar clones were planted on two graded anthracite coal-mine spoils derived from sandstone or from glacial till. Ten-year results show that the plantation survived well (82 percent), but that growth was extremely varied. Spoil characteristics and performance of individual clones are presented.

47. Czapowskyj, Miroslaw M.; Sowa, Edward A. 1976. **Lime helps establish crownvetch on coal-breaker refuse**. Res. Pap. NE-348. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

Lime, fertilizer, and mulch were used on anthracite coal-breaker refuse in an attempt to establish a ground cover of crownvetch. Lime had an effect after 7 years and is considered essential for establishing crownvetch on these highly acid sites. Fertilizer had little effect on survival but enhanced the establishment of ground cover. Mulch also provided some benefit. Chemical characteristics of the refuse were improved on areas that received lime and fertilizer treatments.

48. Davidson, Walter H. 1977. **Birch species survive well on problem coal mine spoils**. In: Proceedings, 24th

northeastern forest tree improvement conference; 1976 July 26-29; College Park, MD. College Park, MD: University of Maryland: 95-101.

Seven species of birches from 10 seed sources were evaluated for survival and growth rates on coal-mine spoils in Pennsylvania. The seedlings were planted on eight highly acid strip-mine spoil areas (pH 3.0 to 3.8), one acid strip-mine area (pH 4.0), and one deep-mine refuse pile (pH 3.3). After 3 years, survival was satisfactory to good on all spoil areas. Three sources had unsatisfactory survival on the deep-mine refuse.

49. Davidson, Walter H. 1977. **Performance of ponderosa pine on bituminous mine spoils in Pennsylvania**. Res. Pap. NE-358. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

In 1969, seedlings from 40 seed sources of ponderosa pine were planted on a strip-mine spoil in central Pennsylvania. Survival of seedlings from different sources ranged from 23 to 90 percent after six growing seasons. The average height of the seedlings ranged from 67 to 140 cm for the same period. Eight sources produced seedlings that were average or above in both height growth and survival.

50. Davidson, Walter H. 1979. **Hybrid poplar pulpwood and lumber from a reclaimed stripmine**. Res. Note NE-282. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 2 p.

A 2-acre hybrid poplar planting on a reclaimed stripmine was harvested at age 16. The commercial clearcut yielded 90 tons of pulpwood and 9,400 board feet of lumber. This is equal to a growth rate of approximately 2 cords per acre per year. Selected physical properties of the hybrid poplars were compared with those of other commercial eastern species.

51. Davidson, Walter H. 1979. **Results of tree and shrub plantings on low pH strip-mine banks**. Res. Note NE-285. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 5 p.

Test plantings were established to evaluate the survival and growth of trees and shrubs on 10 acid strip mines in the bituminous region of Pennsylvania. Included in the test were five species of European alder, four birch species, black locust, sycamore, Scotch pine, autumn olive, sawtooth oak, bristly locust, and Japanese fleeceflower. After 11 years, two of the birches had highest rate of survival and best growth overall. On several plots, European alder from a German seed source performed well; Scotch pine also performed well on several plots. Survival and growth rates of all species generally were poor on spoils where the pH was less than 3.5.

52. Davidson, Walter H. 1980. **Direct seeding for forestation**. In: Trees for reclamation. Gen. Tech. Rep. NE-61. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 93-97.

Direct seeding, although an attractive alternative to planting, is not a simple method of forestation. Well-documented procedures must be followed to ensure any degree of success. In general, conifers provide good results, and black locust can be direct seeded on mine spoils. Current research suggests that direct seeding of other hardwoods also would be successful.

53. Davidson, Walter H. 1981. **Erosion control measures on Appalachian strip-mines**. In: Forest regeneration: proceedings of the symposium on engineering systems for forest regeneration; 1981 March 2-6; Raleigh, NC. Publ. 10-81. St. Joseph, IL: American Society of Agricultural Engineers: 10-14.

Each year, surface mining for coal disturbs approximately 30,000 acres of land in Appalachia. Increasing energy demands likely will result in greater annual disturbances in the future. Most surface mining has taken place on forested lands. With removal of the forest cover and disturbance of the natural soil, the potential for soil erosion is great. The objectives of erosion control on surface mines are twofold: to keep as much soil as possible on the site and to trap or control soil that is eroded to prevent off-site damage. To attain these objectives, a soil stabilization program in conjunction with sediment ponds must be established.

54. Davidson, Walter H. 1981. **Rooting characteristics of grasses on topsoiled surface mines**. In: Graves, Donald H., ed. Proceedings 1981 symposium on surface mining hydrology, sedimentology, and reclamation; 1981 December 7-11; Lexington, KY. Lexington, KY: University of Kentucky: 267-270.

The effectiveness of topsoiling as a reclamation practice to enhance the establishment of herbaceous plants on surface mines was evaluated. Ground cover and root penetration were examined at 390 random sample points located on five sites in the bituminous region of Pennsylvania. Reclamation treatments for each site were documented. Topsoil depth was measured at each point and soil samples were collected for chemical analysis. Root growth for all species examined was primarily in the top two-thirds of the topsoil. On four of the sites, penetration into the minesoil was in the form of single, unbranched roots. On the fifth site, penetration into the minesoil was strong at 68 of the 100 sample points. Soil chemical characteristics showed considerable variation between sites.

55. Davidson, Walter H. 1981. **Timber volumes of old Pennsylvania surface mine reclamation plantations**. Res. Note NE-303. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 5 p.

Surface-mine reclamation plantings established in Pennsylvania from 1919 to 1934 were evaluated to determine merchantable volume, presence and volume of volunteer species, and soil development since planting. Planted conifers had a total volume of 744 Mbf on the 150 acres of reclaimed surface mines. In additional, there were

356 Mbf of volunteer hardwood species on the area. Examination of soil profiles showed development of distinct soil horizons in every plantation.

56. Davidson, Walter H. 1983. **Hybrid poplar sprout clumps: thinning does not improve development**. Journal of Forestry. 81(10): 662-663.

One growing season after the harvest of a 16-year-old hybrid poplar plantation, sprouts from 100 clumps were thinned to retain the dominant sprout; 100 clumps were left for comparison. After three growing seasons, thinned and unthinned clumps did not differ in total number of sprouts per clump or in diameter of dominant sprouts. Dominant sprouts were significantly taller in the unthinned clumps. Thinning hybrid poplar sprout clumps after a harvest is not recommended.

57. Davidson, Walter H. 1985. **Excess moisture decreases survival and retards growth of hybrid pine seedlings**. In: Pope, P. E., comp. Better reclamation with trees: proceedings of the fourth annual conference; 1984 June 7-8; Owensboro, KY. West Lafayette, IN: Purdue University: 135-139.

In 1981, a small plantation of pitch x loblolly pine hybrids was established on a reclaimed surface mine in Boone County, West Virginia. The site was covered with a moderately dense stand of sericea lespedeza and K-31 tall fescue. Rows were rototilled to prepare the site for planting. First-year survival was nearly 100 percent; after 3 years, survival was 92 percent. Mortality of most of the remaining 8 percent can be attributed to excess moisture.

58. Davidson, Walter H. 1986. **A renewed interest in white pine**. Green Lands. 16(2): 32-33.

There is renewed interest in managing eastern white pine for timber production. White pine, which survives and grows well on a wide range of site and climatic conditions, should be considered as a species for reclamation and planting on abandoned mined lands in the Appalachian Region.

59. Davidson, Walter H. 1986. **Predicting tree survival and growth from minesoil analysis**. In: Forests, the world, and the profession: proceedings of the 1986 Society of American Foresters national convention; 1986 October 5-8; Birmingham, AL. Bethesda, MD: Society of American Foresters: 244-246.

In a 1972 study, it was shown that pH was the principal site condition affecting the survival of tree seedlings. But pH alone can suggest only the potential of a site to support vegetation. Many trees survived on sites where soil analyses indicated mortality would occur. Reexamination of several sites in 1986 showed that some trees still were alive on sites where mortality had been predicted. There was some mortality on sites where survival had been predicted. Results of the 1986 soil analyses showed a greater increase in pH on locations with an accumulation of litter than on open soil.

60. Davidson, Walter H. 1986. **Selecting hybrids and superior trees for reclamation planting**. In: New horizons for mined land reclamation: 1986 national meeting of the American Society for Surface Mining and Reclamation; 1986 March 17-20; Jackson, MS. Princeton, WV: American Society for Surface Mining and Reclamation: 165-168.

Tree species used in reclamation plantings should have the highest potential for survival and development on a given mine site. Selection criteria should include the ability to become established under adverse site conditions, rapid early growth, future market value, and freedom from insects and diseases. Field trials have identified several high potential hybrids and species for reclamation plantings. These include hybrid poplar, pitch x loblolly hybrid pine, Virginia pine, Austrian pine, European black alder, and black locust. Recommended hybrid clones and seed sources are listed.

61. Davidson, Walter H. 1987. **Pitch x loblolly hybrid pine performance on a West Virginia minesoil**. In: Demeritt, Maurice E., Jr., ed. Proceedings, 30th northeastern forest tree improvement conference; 1986 July 22-24; Orono, ME. Orono, ME: University of Maine, School of Forest Resources: 96-101.

A small plantation of pitch x loblolly hybrid pine was established in 1981 on a reclaimed surface mine in Boone County, West Virginia. In the test, 215 hybrid and 216 pitch pine seedlings were used from 19 pitch pine mother trees and 24 loblolly pine seedlings. The site was covered with a moderately dense stand of sericea lespedeza and K-31 tall fescue. First-year survival was nearly 100 percent. After 5 years, overall survival was 88 percent. Much of the mortality can be attributed to excess moisture. The average height of hybrids was 4.4 feet after 5 years; 13 percent of the seedlings were 6 feet or taller. Pitch pines averaged 4 feet with only 6 percent of the seedlings 6 feet or taller.

62. Davidson, Walter H. 1988. **Don't write off direct seeding efforts too soon**. In: Graves, Donald H.; DeVore, R. William, eds. Proceedings, 1988 symposium on mining, hydrology, sedimentology, and reclamation; 1988 December 5-9; Reno, NV. Publ. UKY BU148. Lexington, KY: University of Kentucky; College of Engineering: 217-221.

Direct seeding has potential for foresting of minesoils so long as compaction and competition from herbaceous species are not limiting.

63. Davidson, Walter H. 1988. **Potential for planting hardwoods in the Appalachians**. In: Smith, H. Clay; Perkey, Arlyn W.; Kidd, William E., Jr., eds. Guidelines for regenerating Appalachian hardwood stands: workshop proceedings; 1988 May 24-26; Morgantown, WV. SAF Publ. 88-03. Morgantown, WV: West Virginia University Books: 255-268.

Artificial regeneration of hardwoods in the Appalachian Region is a desirable management technique to improve

species composition in existing forest stands and ensure regeneration following harvest cuts. The current knowledge on the artificial regeneration of hardwoods indicates that considerable work has been accomplished in this area and that some techniques can be recommended. However, there are problem areas for which additional research and refinement are required. In areas where artificial regeneration is desired, the need for information on how to achieve it successfully is especially great.

64. Davidson, Walter H. 1989. **First-year evaluation of excelsior pads on loblolly pine**. In: Walker, D. G.; Powter, C. B.; Pole, M. W., eds. Proceedings of the conference: reclamation, a global perspective; 1989 August 27-31; Calgary, AB. Rep. RRTAC 89-2. Calgary, AB: Alberta Land Conservation and Reclamation Council: 339-343.

A study was conducted in the spring of 1988 to test the effects of excelsior pads on the survival and growth of loblolly pine. Two types of pads were used: American Excelsior Company TREGRO type 100 and 200. Bare-root, 1-0 loblolly pine seedlings were mattock-planted on April 14 and the pads installed on April 15. The study design was random pairs of treatment (with pad) and control (no pad) seedlings. An evaluation on May 5 showed inconsistent survival that was attributed to planting technique. Evaluation at the end of the growing season showed that the pads had no apparent influence on survival. Overall survival was 72 percent with pads and 71 percent without pads. Seedlings with the type 200 pads were significantly taller than controls or type 100 seedlings.

65. Davidson, Walter H. 1990. **Effects of superabsorbents on hybrid poplar establishment and growth**. In: 1990 national symposium on mining; 1990 May 14-18; Knoxville, TN. Lexington, KY: University of Kentucky: 27-29.

In 1983, a study was conducted to determine whether superabsorbents enhanced the establishment and subsequent growth of hybrid poplar cuttings. The study was installed on three mine sites: one in southern West Virginia, one in central West Virginia, and one in western Maryland. Fifteen hybrid poplar clones were used. The treatments were two types of superabsorbent and a control. The superabsorbents appeared to improve both establishment and growth, though none of the analyses showed significant differences. Variations within clones seemed to mask the effects of the superabsorbents.

66. Davidson, Walter H. 1991. **Performance of spot-seeded oaks and walnut on an eastern Kentucky minesoil**. International Journal of Surface Mining and Reclamation. 5: 163-165.

Describes the effects of mulch, fertilizer, and grasses and legumes on the survival and growth of four species of spot-seeded oak and walnut after 10 growing seasons.

67. Davidson, Walter H.; Ashby, W. Clark; Vogel, Willis G. 1988. **Progressive changes in minesoil pH over three decades**. In: Mine drainage and surface mine reclamation: proceedings of conference sponsored by American Society for Surface Mining and Reclamation, Bureau of Mines, and Office of Surface Mining Reclamation and Enforcement; 1988 April 19-21; Pittsburgh, PA. Inf. Circ. 9184. Washington, DC: U.S. Department of the Interior, Bureau of Mines: 89-92.

Surface minesoils in the Appalachian and interior Coal Provinces that include a mixture of overburden materials may experience rapid changes of pH in the early years after mining, followed by slow, longer term changes. Reclamation plantings are commonly made on minesoils atypical in pH for the region (extremely acid to moderately alkaline). Subsequent measurements on these plantings, including soil pH, have shown a high degree of regularity in convergence of pH toward values more typical of regional soils. The changes were most prominent in extremely acid soils. One cause of the long-term changes in pH may be the effects of plant cover.

68. Davidson, Walter H.; Freeland, Albert W.; Elison, Bradley. 1990. **Successful oak establishment on a reclaimed surface mine**. In: Skousen, J.; Sencindiver, J.; Samuel, D. eds. Proceedings of the 1990 mining and reclamation conference and exhibition, vol. I; 1990 April 23-26; Charleston, WV. Charleston, WV: West Virginia University: 295-297.

An 8-year-old northern red oak plantation on a reclaimed anthracite surface mine in Pennsylvania was evaluated. Survival exceeded 70 percent and some of the saplings grew 2 feet or more each year. The tallest trees were 14 feet and the plantation averaged 8 feet. The absence of a heavy herbaceous cover, little or no soil compaction, good planting technique, and sufficient moisture contributed to good seedling establishment. The success of this plantation shows that red oak can survive and grow well on reclaimed minesoils.

69. Davidson, Walter H.; Graves, Donald H. 1987. **Opportunities for forestry practices on reclaimed surface mines**. In: Proceedings, 1987 national symposium on mining, hydrology, sedimentology, and reclamation; 1987 December 7-11; Springfield, IL. Publ. UKY BU145. Lexington, KY: University of Kentucky: 327-330.

Forestry is a viable and productive use of reclaimed mined land. Experience in the eastern and central coalfields has shown that productive forests can be established after mining. Proper planting and execution are necessary to achieve successful restoration. Limiting factors such as soil compaction, acidic soils, competition from herbaceous plant materials, and phytotoxic levels of aluminum and manganese can be overcome. Case studies of successful reforestation illustrate the potential of mined lands for forest production.

70. Davidson, Walter H.; Hutnik, Russell J.; Bauman, Randall A. 1987. **Ponderosa pine—a reclamation**

species for the east? In: 4th biennial symposium on surface mining and reclamation on the Great Plains and 4th annual meeting of the American Society for Surface Mining and Reclamation; 1987 March 17-19; Billings, MT. Rep. No. 8704. Bozeman, MT: Montana State University, Reclamation Research Unit: H-8-1 thru H-8-7.

Species trials in which ponderosa pine was used to revegetate acid minesoils in Pennsylvania have met with varying degrees of success. The most extensive study, involving 49 provenances of ponderosa pine, was established in the spring of 1969. After 17 years, overall survival was 57 percent and mean diameter at breast height (d.b.h.) was 2.7 inches. Most of the mortality had occurred within 2 years after planting, but it is increasing again as a result of infection by the western pine gall rust. This disease apparently was present on several seedlings at time of planting. Although the overall performance of the planting is mediocre, some seed sources had significantly better survival, growth, and/or disease resistance than others. The best four sources at plantation age 17 had nearly 80 percent mean survival and averaged 3.8 inches in d.b.h.

71. Davidson, Walter H.; Hutnik, Russell J.; Parr, Delbert E. 1984. **Reforestation of mined land in the Northeastern and North-Central U. S.** Northern Journal of Applied Forestry. 1(1): 7-12.

Reviews surface-mine reclamation efforts in Pennsylvania, Maryland, West Virginia, Ohio, Indiana, and Illinois. Legislative constraints, socioeconomic issues, factors limiting the success of reforestation efforts, postmining 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.

72. Davidson, Walter H.; Pollio, Carol A. 1991. **Woody species establishment from a forest soil seed bank in West Virginia**. In: Oaks, Wendall; Bowden, Joe, eds. Proceedings of the 1991 national meeting of the American Society of Surface Mining and Reclamation; 1991 May 14-17; Durango, CO. Princeton, WV: American Society of Surface Mining and Reclamation: 625-629.

73. Davidson, Walter H.; Riddle, Jane. 1978. **Old strip mine produces. . . new pulpwood crop**. Pennsylvania Forests. 68(2): 18.

A second generation of hybrid poplars is growing on an old strip-mine site in Pennsylvania. The first generation, which averaged 10 inches in diameter and 65 feet in height, was harvested in 1977, primarily for pulpwood and sawlogs. Total volume harvested was about 90 tons of pulpwood and 9,400 board feet of lumber. Established in 1962, the 2-acre plantation is a joint venture between the USDA Forest Service and the Pennsylvania Coal Mining Association.

74. Davidson, Walter H.; Sowa, Edward A. 1982. **Conifers growing on anthracite minesoils respond to fertilization**. In: Proceedings, 1982 symposium on surface mining hydrology, sedimentology, and reclamation; 1982 December 5-10; Lexington, KY. Lexington, KY: University of Kentucky: 115-118.

Studies were conducted in Pennsylvania on anthracite minesoils and breaker refuse to examine the growth response of planted conifers to slow-release fertilizer and granular fertilizer. Annual height growth was used to measure response. Species evaluated were Japanese larch, white spruce, and red, white, Scotch, and Austrian pines. All species except white spruce showed a significant response to the treatments, though actual height differences were relatively small.

75. Davidson, Walter H.; Vogel, Willis G. 1983. **Hybrid poplar for reclamation**. In: Better reclamation with trees: proceedings of the 3rd annual conference; 1983 June 2-3; Terre Haute, IN. West Lafayette, IN: Amax Coal Co. and Purdue University, Department of Forestry: 99-109.

Research on hybrid poplars has shown that some clones have potential for use in minesoil reclamation. The most promising clones are identified. Hybrid poplar can be used for energy plantations and aesthetic plantings. The wood is used for pulp, fuel, construction lumber, furniture, veneer, boxwood, and novelty products. Research on plantation establishment and management, growth rates and timber yields, and utilization is reviewed. The report includes studies conducted in Pennsylvania, Maryland, West Virginia, Kentucky, and Ohio.

76. Demeritt, Maurice E., Jr. 1988. **Seed and seedlings for the spruce-fir research cooperative**. In: Hertel, Gerard, tech. coord. Proceedings of the US/FRG research symposium: effects of atmospheric pollutants on the spruce-fir forests of the Eastern United States and the Federal Republic of Germany; 1987 October 19-23; Burlington, VT. Gen. Tech. Rep. NE-120. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 67-68.

Seed or seedlings of known origin are provided to investigators in the size, quantity, time, pot, and/or physiological condition necessary to optimize experiments. Except for unusual circumstances, all seed and seedlings are handled under uniform environmental protocols.

77. Drnevich, Vincent P.; Ebelhar, Ronald J.; Williams, G. Perry, Jr. 1976. **Geotechnical properties of some eastern Kentucky surface mine spoils**. Ohio River Valley Soils Seminar Proceedings. 1-1-1-13.

The relationship between dry density, moisture content and plasticity, and shear strength were significantly different for mine spoils than for soil. Permeabilities for spoils were four orders of magnitude lower than for soils of similar indices. Measurements of effective and total stress showed that spoils have more shear strength in the short term but less shear strength in the long term than soils with similar index properties.

78. Drnevich, Vincent P.; Williams, G. Perry, Jr.; Ebelhar, Ronald J. 1976. **Soil mechanics tests on coal mine spoils**. In: Proceedings, 2nd Kentucky coal refuse disposal and utilization seminar; 1976 May 20-21; Pineville, KY. Lexington, KY: University of Kentucky, Institute for Mining and Mineral Research: 47-59.

Study results showed that conventional tests for shear strength and permeability are suitable for use on mine spoils. Test data on spoils showed trends similar in direction but different in degree from those on soils with similar index properties. Test data can be used to develop and rank alternative mining plans.

79. Dyer, Kenneth L. 1982. **Stream water quality in the coal region of Alabama and Georgia**. Gen. Tech. Rep. NE-73. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 109 p.

Data collected in 1977-79 from 20 small streams that drain unmined watersheds and 38 that drain areas where coal has been surface mined include common ions, alkalinity, acidity, pH, 16 trace elements, five nitrogen and phosphorous species, specific conductance, suspended solids, turbidity, settleable matter, water temperature, and estimated discharge.

80. Dyer, Kenneth L. 1982. **Stream water quality in the coal region of eastern Kentucky**. Gen. Tech. Rep. NE-74. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 208 p.

Data collected in 1977-79 from 38 small streams that drain unmined watersheds and 86 that drain areas where coal has been surface mined include common ions, alkalinity, acidity, pH, 16 trace elements, five nitrogen and phosphorous species, specific conductance, suspended solids, turbidity, settleable matter, water temperature, and estimated discharge.

81. Dyer, Kenneth L. 1982. **Stream water quality in the coal region of Ohio**. Gen. Tech. Rep. NE-75. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 138 p.

Data collected in 1977-79 from 19 small streams that drain unmined watersheds and 50 that drain areas where coal has been surface mined include common ions, alkalinity, acidity, pH, 16 trace elements, five nitrogen and phosphorous species, specific conductance, suspended solids, turbidity, settleable matter, water temperature, and estimated discharge.

82. Dyer, Kenneth L. 1982. **Steam water quality in the coal region of Pennsylvania**. Gen. Tech. Rep. NE-76. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 168 p.

Data collected in 1977-79 from 29 small streams that drain unmined watersheds and 57 that drain areas where coal has been surface mined include common ions, alkalinity, acidity, pH, 16 trace elements, five nitrogen and phosphorous species, specific conductance, suspended solids, turbidity, settleable matter, water temperature, and estimated discharge.

83. Dyer, Kenneth L. 1982. **Stream water quality in the coal region of Tennessee**. Gen. Tech. Rep. NE-77. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 125 p.

Data collected in 1977-79 from 17 small streams that drain unmined watersheds and 51 that drain areas where coal has been surface mined include common ions, alkalinity, acidity, pH, 16 trace elements, five nitrogen and phosphorous species, specific conductance, suspended solids, turbidity, settleable matter, water temperature, and estimated discharge.

84. Dyer, Kenneth L. 1982. **Stream water quality in the coal region of Virginia**. Gen. Tech. Rep. NE-78. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 68 p.

Data collected in 1977-79 from 12 small streams that drain unmined watersheds and 19 that drain areas where coal has been surface mined include common ions, alkalinity, acidity, pH, 16 trace elements, five nitrogen and phosphorous species, specific conductance, suspended solids, turbidity, settleable matter, water temperature, and estimated discharge.

85. Dyer, Kenneth L. 1982. **Stream water quality in the coal region of West Virginia and Maryland**. Gen. Tech. Rep. NE-70. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 215 p.

Data collected in 1977-79 from 48 small streams that drain unmined watersheds and 79 that drain areas where coal has been surface mined include common ions, alkalinity, acidity, pH, 16 trace elements, five nitrogen and phosphorous species, specific conductance, suspended solids, turbidity, settleable matter, water temperature, and estimated discharge.

86. Dyer, Kenneth L. 1983. **Effects on water quality of coal mining in the basin of the North Fork Kentucky River, eastern Kentucky**. Water Resour. Invest. Rep. 81-215. Louisville, KY: U.S. Geological Survey. 94 p.

The effects of mine drainage on stream-water quality were investigated on the watershed of the North Fork Kentucky River in 1975. Measurements of specific conductance were taken at 415 sites. In addition, discharge, pH values, and sulfate and data on chloride were obtained.

87. Dyer, Kenneth. 1983. **pH in streams draining small mined and unmined watersheds in the coal region of Appalachia**. Res. Note NE-314. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 6 p.

To better evaluate the effects of surface mining for coal in first-order watersheds in Appalachia, a network of 421 water-quality sampling stations was established in 136 counties in nine states in 1977 and sampled on approximately a monthly basis until August 1979. Three categories of watersheds were sampled: (1) unmined, (2) mined after January 1972, and (3) mined before January 1972. Mean pH values were 7.0, 6.7, and 6.3 for these three categories of watersheds, respectively.

88. Dyer, Kenneth L. 1984. **Water, friend or foe in the control of acid mine drainage**. In: Surface mining and water quality: proceedings, 5th annual West Virginia surface mine drainage task force symposium; 1984 March 21-22; Morgantown, WV. Charleston, WV: West Virginia Mining and Reclamation Association: 1-16.

Water has traditionally been considered an enemy in the battle to halt the formation and transport of acid-mine drainage, so efforts and laws have been directed at keeping water from toxic spoil materials. It is becoming increasingly clear that even the most stringent measures for keeping water from toxic spoils have not fully prevented the formation and transport of acid-mine drainage. There is ample evidence that immersing toxic spoils under water not only can prevent the formation of drainage, and/or remove it from solution under certain circumstances.

89. Dyer, Kenneth L. 1986. **Seasonal acid mine drainage from a surface-mined watershed in eastern Kentucky**. In: New horizons for mined land reclamation: 1986 national meeting of the American Society for Surface Mining and Reclamation; 1986 March 17-20; Jackson, MS. Princeton, WV: American Society for Surface Mining and Reclamation: 131-139.

Jacks Branch and nearby streams in Knott County, in eastern Kentucky, experienced highly acidic “flushouts” during spring runoff events, but were nearly neutral or alkaline for the rest of the year. Discharges were the most acidic and saline several hours or days following peak discharge; the least saline discharges occurred near the discharge peaks due to dilution. The pH of Jacks Branch ranged from 2.7 to 8.1; dissolved solids ranged from 491 to 3,000 mg/l. Two seams of coal have been mined on the watershed, the lower by auger mining and the upper by both strip and auger mining. Strong permanent springs emerged from the lower seam of coal, assuring a dependable supply of good-quality, nearly neutral or alkaline water in the main stream at base flow. During periods of high flow in the spring, highly acidic drainage from the upper mined area seriously degraded water quality of the main stream.

90. Dyer, Kenneth L.; Crews, Jerry T. 1986. **Evaluation of Bentonite for the control of acid drainage from surface-mined lands, part 2**. In: Proceedings, 7th annual West Virginia mine drainage task force symposium; 1986 April 1-2; Morgantown, WV. Charleston, WV: West Virginia Mining and Reclamation Association. 1-16.

Sodium bentonite absorbs nearly five times its weight in water. At full saturation, it occupies a volume nearly 15 times its dry bulk. The key to the expansion and water-sealing action of bentonite lies in its structure. The clay flake is composed of dry crystalline sheets so minute that when completely dispersed in water, a cubic inch of dry bentonite subdivides into nearly 10 billion flakes with a combined surface area of nearly an acre. Bentonite cannot be used to impede the flow of salty or acid water because it loses its swelling power and, therefore, its sealing power when in contact with such water.

91. Dyer, Kenneth L.; Curtis, Willie R. 1977. **Effect of strip mining on water quality in small streams in eastern Kentucky, 1967-1975.** Res. Pap. NE-372. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 13 p.

Eight years of streamflow data were analyzed to determine the effects of strip mining on the chemical quality of water in six first-order streams in Breathitt County, Kentucky. The data indicate that strip mining causes large increases in the concentration of most major dissolved constituents in the runoff waters. Maximum concentration of dissolved salts occurred during the low flow of the dormant season; maximum salt loads occurred during the high flow of the early part of the growing season.

92. Dyer, Kenneth L.; Curtis, Willie R.; Crews, Jerry T. 1984. **Response of vegetation to various mulches used in surface mine reclamation in Alabama and Kentucky—7-year case history.** Gen. Tech. Rep. NE-93. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 11 p.

Five mulches and one mulch-amendment combination were evaluated in the reclamation of mine spoils, in western Kentucky and northern Alabama. The treatments evaluated were bark, hardwood chips, straw, hay, hydromulch, and hydromulch plus Petroset SB emulsion. In the first years of the study, bark, hay, and straw generally produced the best vegetative cover. Mulches high in biomass tended to favor the establishment of legumes over grass. After 7 years, the effects of the different mulch treatments were readily apparent at the Alabama site, where the hardwood-chip plot had strikingly superior cover. Differences at the Kentucky site were not so apparent.

93. Dyer, Kenneth L.; Sencindiver, John C. 1985. **Bark mulch promotes establishment of vegetation on minesoils with south and west exposures.** In: Proceedings, 1985 symposium on surface mining, hydrology, sedimentology, and reclamation; 1985 December 9-13; Lexington, KY. Publ. UKY BU139. Lexington, KY: University of Kentucky: 151-156.

In early July 1976, a non-topsoiled head-of-hollow fill in Breathitt County, Kentucky, was seeded to grasses and legumes. From July 12 to July 16, a hardwood bark mulch was applied in a band around this fill. In late August 1976,

the mulched areas were nearly fully sodded, regardless of aspect. South- and west-facing unmulched slopes were nearly void of vegetation. At this time, the north-facing slope had the best vegetative cover even though no mulch had been applied. By the end of the second growing season, nearly the entire head-of-hollow fill was well vegetated, regardless of aspect or whether mulch had been applied. The mulch protected the exposed minesoil from erosion during the first year and speeded the establishment of vegetative cover on the south- and west-facing slopes.

94. Gentry, Claude E.; Halverson, Howard G.; Wade, Gary L. 1991. **Mass of ions by leaching mine spoil with simulated precipitation**. In Oaks, Wendall; Bowden, Joe, eds. Proceedings of the 1991 national meeting of the American Society of Surface Mining and Reclamation; 1991 May 14-17; Durango, CO. Princeton, WV: American Society of Surface Mining and Reclamation: 87-95.

A pyritic coal-mine spoil was leached with simulated precipitation adjusted to pH values of 5.6, 5.0, 4.6, 4.2, and 3.8. Each mine-spoil column contained 1,500 g of recently dug, extremely acid spoil material. Results suggest that fresh spoil contributes readily available ions to groundwater leachate. The pH of incident precipitation significantly affects leaching losses of some elements from mine spoils.

95. Gentry, Claude E.; Willis, Raymond B. 1988. **Improved method for automated determination of ammonium in soil**. Communications in Soil Science and Plant Analysis. 19(6): 721-737.

An improved sodium salicylate-hypochlorite, automated method for ammonium in soil extracting solutions using nitroprusside as catalyst was investigated. This method is 2 to 3 times more sensitive than previously published procedures and also is less subject to interferences, has less noise in the signal, and has two alternative ranges. The range with maximum sensitivity is linear to about 2.5 ppm; the second range is linear to 9 ppm. The procedures and instrumentation are simple for both ranges.

96. Halverson, Howard G. 1988. **High-altitude photography to evaluate coal-mine reclamation**. In: Greer, Jerry D., ed. Remote sensing for resource inventory, planning, and monitoring: proceedings of the 2nd Forest Service remote sensing applications conference; 1988 April 11-15; Slidell, LA. Falls Church, VA: American Society for Photogrammetry and Remote Sensing: 360-365.

Images of four mines were examined with National High-Altitude Program photographs taken between 1981 and 1985. In each case, areas of the mines that appeared dark on the photograph have resisted reforestation. This qualitative study did not isolate the cause of the image color or the elimination of vegetation. Pyrite oxidation resulting in the production of iron oxide and sulfuric acid is a possible explanation for both effects.

97. Halverson, Howard G. 1990. **Qualitative assessment of mined land recovery by remote sensing**. In: Protecting natural resources with remote sensing: proceedings of the 3rd forest service remote sensing applications conference; 1990 April 9-13; Tucson, AZ. Bethesda, MD: American Society for Photogrammetry and Remote Sensing: 392-398.

The Airborne Science and Applications Program sponsored an ER-2 aircraft photography mission in eastern Kentucky in September 1989. Six flight lines were flown over the Redbird Ranger District of the Daniel Boone National Forest. The Redbird District is in the eastern Kentucky coal region and has a long history of mining.

98. Halverson, Howard G.; Gentry, Claude E. 1990. **Long-term leaching of mine spoil with simulated precipitation**. In: Skousen, J.; Sencindiver, J.; Samuel, D., eds. Proceedings of the 1990 mining and reclamation conference and exhibition; 1990 April 23-26; Charleston, WV. Morgantown, WV: West Virginia University: 27-32.

Fresh mine spoil at pH 3.84 was collected and transferred to leachate columns in early August 1988. The spoil was leached weekly with simulated precipitation at pH 5.6, 5.0, 4.6, 4.2, and 3.8. Control samples of mine spoil were simultaneously leached with distilled water at pH 6.47. Leachate was collected and analyzed by standard methods for cations, anions, conductivity, and pH. Cations and anions of major interest were iron, aluminum, manganese, and sulfate. The leachate initially was pH 2.1 with a conductivity of about 10,000 micromho. Concentrations of Fe, Al, Mn, and $S0_4$ were greater than 4,000, 300, 400, and 24,000 mg L^{-1}, respectively. Contaminant levels in the leachate dropped rapidly early in the leaching regime. After 4 weeks, pH increased slightly to 212, conductivity declined to about 7,000, and ionic concentrations declined to averages of 1,300 for Fe, 170 for Al, 175 for Mn, and 16,000 for $S0_4$. In the following weeks, contamination in the leachate continued to decline but at a lesser rate.

99. Halverson, Howard G.; Sidle, Roy C. 1992. **Cumulative effects of mining on hydrology, water quality, and vegetation.** In: Chambers, Jeanne C.; Wade, Gary L., eds. Evaluating reclamation success: the ecological consideration–proceedings of a symposium; 1990 April 23-26; Charleston, WV. Gen. Tech. Rep. Rep. NE-164. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 99-104.

Evaluating the cumulative effects of mining and other land disturbances at the watershed scale poses a challenge for researchers and practitioners. Offsite cumulative effects may arise due to multiple mining disturbances occurring simultaneously within a watershed, or from the interaction of mining activities and adjacent land uses (grazing, residential development, recreation, timber harvest). Progressive surface and underground mining may generate onsite cumulative effects by modifying soil and vegetation composition, slope stability, and surface erosion potential.

100. Halverson, Howard G.; Wade, Gary L. 1988. **Chemical variation in acid mine drainage in southern Kentucky**. In: Graves, Donald H.; De Vore, R. William, eds. Proceedings, 1988 Symposium on mining, hydrology, sedimentology, and reclamation; 1988 December 5-9; Reno, NV. Publ. UKY BU148. Lexington, KY: University of Kentucky, College of Engineering: 95-104.

Acid mine drainage is a major environmental concern in much of the Eastern United States. The water quality of five seeps from coal seams in southeastern Kentucky was monitored from the spring of 1987 until the spring of 1988. One watershed had three seep sources and one watershed had two. Analyses were conducted for various anion and cation concentrations as well as pH, conductivity, and acidity. The data showed that variables such as pH, Fe, Al, sulfate, and many other constituents differed significantly among seeps. However, the water quality of individual seeps was consistent over time.

101. Helvey, J. David; Kochenderfer, James N. 1991. **Time trends in selected chemical characteristics of streamflow from an undisturbed watershed in West Virginia.** In: Rennie, P. J.; Robitaille, G., eds. Effects of rain on forest resources; June 14-17; Sainte-Foy, PQ. Inf. Rep. DPC-X-35. Ottawa, ON: Forestry Canada: 429-437.

Records of stream chemistry for a 38.9-ha watershed, undisturbed since 1910, were analyzed for time trends in pH between 1968 and 1982, specific conductance between 1958 and 1982, and concentrations of calcium, magnesium, potassium, and sodium between 1970 and 1982. Changes in pH were small, though the analysis was inconclusive. There was no change in levels of sodium, potassium, or magnesium. Specific conductance and calcium concentrations increased slightly.

102. House, Michael C. 1977. **Determination of relationships between climate, relief, species, and spoil material on tree development and soil formation at three locations in eastern Ohio.** Columbus, OH: Ohio State University. M.S. thesis.

103. Hutnik, R. J.; Davis, Grant. 1978. **Reclamation of coal mined land in the United states as compared with the Ruhr.** In: Goodman, Gordon T.; Chadwick, Michael J., eds. Environmental management of mineral wastes. Alphen aan den Rijn, T
he Netherlands: Sijthoff and Noordhoff: 71-83.

Reclamation practices in the United States differ from those in the Ruhr district of Germany mostly because of differences in geography and mining laws. Surface mining, underground mining, and open-pit operations are prominent throughout U.S. coal fields, while cut underground mining is prevalent in the Ruhr district.

104. Keys, Roy N.; Cech, Franklin C.; Davidson, Walter H. 1981. **The performance of Austrian pine seed sources on various sites in West Virginia and Pennsylvania**. In: Proceedings, 27th northeastern forest tree improvement conference; July 29-31; Burlington, VT. Burlington, VT: University of Vermont: 103-114.

Twelve sources of Austrian pine were tested on five mine spoils and one agricultural site. Lime or fly ash application enhanced the planting survival on extremely acid sites. In West Virginia, survival of Austrian pine was best at about 2,500 feet above sea level.

105. Keys, Roy N.; Cech, Franklin C.; Davidson, Walter H. 1986. **Nutrient content and growth of an Austrian pine (*Pinus nigra* Arnold), seed source study on surface mine spoils**. In: Proceedings, 1986 national symposium on mining, hydrology, sedimentology, and reclamation; 1986 December 8-11; Lexington, KY. Publ. UKY BU142. Lexington, KY: University of Kentucky: 267-274.

Foliage was collected from eight Austrian pine seed sources growing on four reclaimed surface mines, a reclaimed deep mine refuse dump, and an agricultural site. Analysis of the foliage nutrient content showed differences among sites and seed sources for most of the nutrients tested, and some site x source interactions. There were significant correlations of tree growth with foliage nutrient content and with soil nutrient content for several elements.

106. Larson, M. M. 1984. **Invasion of volunteer tree species on stripmine plantations in east-central Ohio**. Res. Bull. 1158. Wooster, Ohio: Ohio State University, Ohio Agricultural Research and Development Center. 10 p.

The species and density (number and basal area per acre) of volunteer trees in 30-year-old stands of white pine, black locust, white ash, and yellow-poplar were determined on three strip-mine areas, each of a different spoil type. The number of volunteer trees varied with spoil type, with 929 trees/acre on nearly neutral spoils derived from glacial till and sandstone, 698 trees/acre on acidic (pH 3.8 to 5.5) shaly sand spoil, and 516 trees/acre on calcareous limestone and clay spoil. Black cherry seedlings were the predominant volunteers on neutral and acidic spoils, while black locust and white ash predominated on the calcareous clay spoil.

107. Larson, M. M.; Vimmerstedt, J. P. 1983. **Evaluation of 30-year-old plantations on stripmined land in east central Ohio**. Res. Bull. 1149. Wooster, OH: Ohio State University, Ohio Agricultural Research and Development Center. 10 p.

Thirteen experimental plantations established by the USDA Forest Service in 1946-47 on strip-mined land in eastern and southeastern Ohio were remeasured in 1975-76. Survival of all planted trees averaged 36.6 percent on calcareous spoil and 23.3 percent on noncalcareous spoil after 30 years. White and green ash survived best of the planted species; white pine was largest in diameter. Tuliptree was tallest of all species tested but was sensitive to soil compaction by grading and had comparatively low survival. Black locust was effective in site stabilization but stand vigor

is declining rapidly on most areas due to heavy borer damage. Growth of hardwoods was not improved when planted in various mixtures with black locust. Pine and hardwood transplants tended to survive better than seedlings, though vigor of stock was more important than age or class. Survival of bur oak was outstanding among species that were direct seeded, especially on south slopes of spoil banks. The survival and growth of legume and grass cover were spotty even during the earliest years.

108. Mardon, David N.; Rothwell, Frederick M. 1985. **An *Azospirillum lipoferum* isolate with high nitrogen-fixing capabilities from a coal surface-mined site**. Transactions of the Kentucky Academy of Science. 46(1-2): 33-35.

Azospirillum lipoferum was isolated from the rhizosphere soil of *Festuca arundinacea* growing on a coal surface-mined site in eastern Kentucky. As measured by the acetylene reduction assay, this isolate fixed nitrogen at a substantially higher rate compared with other *Azospirillum* cultures. These results demonstrate the potential significance of associative nitrogen-fixation in establishing and maintaining the growth of herbaceous vegetation on minesoils when nitrogen is a limiting factor.

109. McGuire, John R. 1977. **There's more to reclamation than planting trees**. American Forests. 83(7): 14-19.

The USDA Forest Service's reclamation research program is designed to provide the scientific information needed to plan efficient mining operations that will have a minimum impact on forest resources. These practices will leave disturbed areas in the best possible conditions for rapid reclamation and restore forest resources, compatible with adjacent land use, as rapidly as possible.

110. Melhuish, J. H., Jr.; Beckjord, P. R.; Vogel, W. G. 1987. **Flowering requirements of *Tussilago farfara***. Transactions of the Kentucky Academy of Science. 48(1-2): 1-4.

Tussilago farfara L. (coltsfoot) has become naturalized and is found on disturbed and waste areas in the Northeastern United States. As a result, it may have potential for use in surface-mine reclamation. Seeding would be more practical and economical than planting rhizomes, but fresh seeds are viable only for about a month, interfering with planting schemes. Flowers can be generated uniformly by placing mature plants in cold storage for 3 months any time of year to generate seeds when needed for various revegetation/ reclamation planting schemes.

111. Melhuish, J. H., Jr.; Gentry, C. E.; Beckjord, P. R. 1990. ***Paulownia tomentosa* seedling growth at differing levels of pH, nitrogen, and phosphorus**. Journal of Environmental Horticulture. 8(4): 205-208.

The effects of various levels of acidity, nitrogen, and phosphorus on the survival and growth of *Paulownia tomentosa* seedlings were examined. The seedlings grew within a pH range of 7.0 to 4.0, but there was little or no growth at pH 3.0. The seedlings grew well with nitrogen at 50 to 200 ppm and phosphorus at 5 ppm, but growth was greatly reduced below 10 ppm nitrogen.

112. Melhuish, J. H., Jr.; Wade, G. L. 1986. **Effect of soil phenolic compounds on growth and fatty acid composition of *Pisolithus tinctorius***. Transactions of the Kentucky Academy of Science. 46(3-4): 128-132.

One to 1,000 u mol/L of ferulic, p-coumaric, and vanillic acids in liquid growth media decreased growth (dry-weight production), increased total lipids as percent of dry weight, and lowered the 18:1 to 18:2 fatty acid ratio in the ectomycorrhizal fungus *Pisolithus tinctorius*. Vanillic acid affected the fatty acid ratios only at the higher concentrations tested. Nutrient concentrations that were 2 and 3 times the normal level reduced growth but partly offset some of the effects of ferulic acid. These results suggest that phenolic compounds produced by some higher plants may cause alteration of growth and liquid synthesis in *P. tinctorius*.

113. Melhuish, John H., Jr.; Wade, G. L.; Baker, C. J. 1984. **Degradation of synthetic glucose-ammonium tartrate liquid medium during autoclaving**. Mycologia. 76(1): 161-162.

Glucose-ammonium tartrate has long been used in culture media for fungi. Large volumes of a glucose-ammonium tartrate in flasks were autoclaved. Upon cooling, a patchy, oil-like film formed on the surface of the medium that developed into a dark brown, short, thread-like precipitate. When the media surface area to air volume in the flasks fell below 0.16, a film and/or precipitate was observed. Preventing precipitate formation by keeping the media surface area to air volume ratio above 0.16 may preclude undesirable effects.

114. Melhuish, J. H., Jr.; Willis, R. B.; Wright, C. S.; Chew, J. 1986. **Separation and identification of phenolic acids and related compounds by gas chromatography and Fourier transform infrared spectroscopy**. Journal of Chemical Ecology. 13(2): 317-323.

Phenolic acids and related compounds were separated by gas chromatography using three separate columns. One of these columns was coupled to a Fourier transform infrared spectrometer. The trimethylsilyl derivatives could be separated and identified by comparing the relative retention times of the three columns. However, where there was overlap, the accompanying infrared data clearly distinguished between the questionable derivatives, enabling characterization of all derivatives.

115. Northeastern Forest Experiment Station. 1980. **Trees for reclamation**. Gen. Tech. Rep. NE-61. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 135 p.

A collection of 30 papers presented at the symposium on trees for reclamation in the Eastern United States held on October 27-29, 1980, in Lexington, Kentucky.

116. Northeastern Forest Experiment Station. 1983. **Forest research–Berea, Kentucky.** NE-INF-55-83. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 12 p.

Describes the nation's most comprehensive effort on surface-mine reclamation at the Northeastern Forest Experiment Station's Laboratory at Berea, Kentucky. Scientists at Berea are developing practical and cost-effective methods to reduce damage to the environment and forest resources from surface mining, and to reclaim newly mined and abandoned mined areas for the benefit or enhancement of water quality, timber, wildlife, recreation, range, and aesthetic values.

117. Plass, William T. 1976. **Direct seeding of trees and shrubs on surface-mined lands in West Virginia**. In: Utz, Keith A., ed. Proceedings of conference on forestation of disturbed areas; 1976 April 14-16; Birmingham, AL. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southeastern Area, State and Private Forestry: 32-42.

Thirty-four tree and shrub species were direct seeded on five sites during a 3-year period. Results indicated that some species should be tested further. These include bicolor lespedeza, false indigo, green ash, Virginia pine, shortleaf pine, and loblolly pine.

118. Plass, William T. 1977. **Growth and survival of hardwoods and pine interplanted with European alder**. Res. Pap. NE-376. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 10 p.

European black alder is recommended for planting on many surface-mine spoils in the Eastern United States. It grows rapidly on a range of spoil types and contributes to soil enrichment by fixing nitrogen and providing a leaf fall rich in nutrients. This study evaluated the effect of alder on the survival and growth of five hardwood and five pine species. After 10 growing seasons, alder had little effect on the survival of the interplanted species, though their height and diameter growth were greater in association with alder. Foliar analyses showed that the interplanted species has used nitrogen fixed by the alder.

119. Plass, William T. 1977. **Seeding and planting to achieve land management objectives**. In: Considine, D. M., ed. Energy technology handbook. New York: McGraw-Hill: 1-102-1-116.

Reclamation practices in the United States are summarized. Topics include site evaluation and preparation, seeding and planting, and land-management options.

120. Plass, William T. 1978. **Reclamation of coal-mined land in Appalachia**. Journal of Soil and Water Conservation. 33(2): 56-61.

During the past decade, improvements in reclamation technology in the Appalachian Region have been accomplished through the efforts of concerned individuals from several states representing governmental, educational, and industrial interests. These accomplishments have created growing optimism regarding the revegetation of surface-mined land. Additional research and experience will determine practical land-use options for mining disturbance.

121. Plass, William T. 1978. **The establishment and maintenance of vegetation on minesoils in the eastern United States**. In: Wali, Mohan K., ed. Ecology and coal resource development. New York: Pergamon Press: 431-437.

Reviews current reclamation practices in the Eastern United States, the factors that contribute to the development of today's technology, and future trends in reclamation research.

122. Plass, William. 1978. **Use of mulches and soil stabilizers for land reclamation in the eastern United States**. In: Reclamation of drastically disturbed lands. Madison, WI: American Society of Agronomy: 329-337.

The use of a mulch or soil stabilizers should be considered as one of several treatment options in reclamation plans for drastically disturbed areas. In the Eastern United States, these materials often are applied to control erosion and aid in the establishment of vegetation. Mulches include raw residues from agricultural or industry, processed residues, and manufactured products. The use of soil stabilizers on drastically disturbed areas is becoming more widely accepted. Treatments may include mulches or soil stabilizers alone or in combination, and should be based on requirements for erosion control, site and climatic variables that may affect vegetation establishment, and the cost of achieving objectives for site protection.

123. Plass, William T. 1979. **The use of southern pines for surface-mine reclamation.** In: Proceedings of symposium on the management of pines of the interior South. Tech. Publ. SA-TP-2. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southeastern Area, State and Private Forestry: 176-182.

Pines of the interior South are native to much of the Appalachian and Interior coal provinces and have been used widely for mined-land reclamation. Species recommendations often are site specific and recognize location, site characteristics, properties of minesoil, compatibility with other vegetation, and land-use objectives. The basic technology does not differ significantly from that used on natural soils.

124. Plass, William T. 1982. **Organic and inorganic amendments affect vegetation growth on an acidic minesoil**. Res. Pap. NE-502. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 7 p.

Shredded hardwood bark, composted municipal waste, and a tannery waste were applied to an acidic minesoil. Supplemental inorganic amendments including fertilizer, agricultural lime, and an alkaline waste from an $S0_2$ scrubber system were applied alone and in combination with the organic amendments. Treatment comparisons were based on vegetation response and chemical and physical characteristics of the minesoil after treatment. Organic amendments are not required for establishing vegetation, though some reduced the time required to produce an acceptable cover.

125. Plass, William T. 1987. **Runoff and sediment yield following mulch and soil stabilizer treatments**. In: 4th biennial symposium on surface mining and reclamation on the great plains and 4th annual meeting of the American Society for Surface Mining and Reclamation; 1987 March 17-19; Billings, MT. Reclam. Res. Unit Rep. No. 8704. Bozeman, MT: Montana State University: G-6-1- G-6-10.

Provides a basis for comparing the effectiveness of 26 mulch and soil stabilizer treatments in reducing surface runoff and sediment yield. Square plots with no vegetative cover, a surface area of 4 m^2, and a slope of 10 degrees were used in this field study. Surface runoff and sediment yield were measured after rainfall events. Results indicate that treatments may increase plant available moisture and reduce seed loss attributed to surface runoff or wind.

126. Pogge, Franz L. 1979. **Review of "Plant performance on surface coal mine spoil in Eastern United States".** Castanea. 44(2): 126-127.

This practical guide discusses the performance of particular trees, shrubs, vines, brambles, grasses, legumes, and forbs when used to fertilize very acid, acid, or slightly acid mine spoils. Fertilizer requirements also are discussed.

127. Rafaill, Barbara L.; Vogel, Willis G. 1978. **A guide to vegetating surface-mined lands for wildlife in eastern Kentucky and West Virginia**. Publ. FWS/OBS-78/84. [Place of publication unknown]: U.S. Department of Interior, Fish and Wildlife Service, Office of Biological Services. 89 p.

Provides information on plant-wildlife relationships and list plants suitable for revegetating surface-mined sites for wildlife in eastern Kentucky and West Virginia. Tolerances of plant species to various environmental factors common to surface mines are identified, planting techniques evaluated, and planting patterns beneficial to wildlife discussed. Because availability of planting stock has often been a limiting factor in revegetation efforts, information on sources of supply is included. Basic requirements of wildlife habitat also are discussed.

128. Richards, T. W.; McComb, W. C.; Vogel, Willis G. 1985. **Seed predation reduces stocking of northern red oak direct-seeded on revegetated mine sites**. In: Pope, P. E., ed. Better reclamation with trees: proceedings of the 4th annual conference; 1984 June 7-8; Owensboro, KY. West Lafayette, IN: Purdue University: 152-159.

Northern red oak acorns were direct seeded on four 10-year-old mine sites in eastern Kentucky. Two sites were dominated by tall fescue and two were vegetated with 10-year-old black locust stands with a crownvetch ground cover. One objective of this study was to quantify seed loss by rodents in different cover types. Four replications of 25 planting spots were established on each site in 1983. White-footed mice were known to inhabit the sites and were suspected of eating planted tree seeds. A live trapping grid was established on each site to estimate mouse populations and compare populations with tree-seed predation. Seed loss on three of the sites was greater than 95 percent; one site had only 75-percent seed predation.

129. Rothwell, Frederick M. 1984. **Aggregation of surface mine soil by interaction between VAM fungi and lignin degradation products of lespedeza**. Plant and Soil. 80: 99-104.

The external mycelium of a vesicular-arbuscular mycorrhizal fungus was effective in aggregating a sandy loam minesoil. The polysaccharide nature of the soil binding agent on hyphal surfaces and on the surfaces of sand particles in contact with the hyphae within the aggregate was demonstrated with the periodic acid-Schiff reagent staining reaction. A possible stabilizing mechanism for macroaggregates was proposed that involves a coupling reaction between glucosamines in the hyphal walls of the fungus with phenolic compounds released during lignin degradation of root tissue of sericea lespedeza root tissue.

130. Rothwell, Frederick M. 1987. **Transformation and decomposition of lignin-related compounds by microbial isolates from mine soils**. Plant and Soil. 104: 143-146.

Spectrophotometric, chromatographic, and ion-exchange procedures were used to follow microbial transformation and degradation of lignin-related compounds during incubation in liquid culture. Analyses of solvent extracts from fermentation media showed that selected minesoil microorganisms were able to modify one or more of the structural components of vanillic and ferulic acids, including methoxyl groups, carbon side-chains, and aromatic rings.

131. Rothwell, Frederick M.; Eagleston, Don. 1985. **Microbial relationships in surface-mine revegetation**. In: Symposium on the reclamation of lands disturbed by surface mining: a cornerstone for communication and understanding: 1984 national meeting of the American

Society for Surface Mining and Reclamation; 1984 July 10-13; Owensboro, KY. Wilmington, DE: Science Reviews: 94-113.

The establishment and interrelationships of microorganisms with soil and plant processes during reclamation are greatly influenced by the composition of the planting medium and vegetation practices. Although the parent material can be used as the vegetation medium, the practice of topsoiling, particularly the direct-haul method, may be beneficial in introducing microorganisms and improving the quality of the plant growth medium of spoils that are chemically or physically less desirable than the native soils. The influence of different vegetation types on soil development on surface mines may be a reflection of physiological differences that affect microbial development in the rhizosphere.

132. Rothwell, Frederick M.; Hacakaylo, Ed; Fisher, Dave. 1983. **Ecto- and endomycorrhizal fungus associations with *Quercus imbricarial***. Plant and Soil. 71: 309-312.

Ten seedlings were collected from 1-year-old shingle oak grown in fumigated and fertilized seedbeds at a tree nursery in western Kentucky. Root material from the seedlings was washed free of soil and small segments stained for microscopic analysis of mycorrhizae development. External morphology of rooted segments was typically octomycorrhizal, with characteristic hyphal mantle and Hartig net development evident in transverse sections of young ectomycorrhizae. In addition, a *Glomus* species frequently was observed in the root cortex.

133. Rothwell, Frederick M.; Holt, Coleman. 1978. **Vesicular-arbuscular mycorrhizae established with *Glomus fasciculatus* spores isolated from the feces of cricetine mice**. Res. Note NE-259. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 4 p.

Cricetine mice were trapped on two revegetated surface-mined areas, one with a freshly seeded grass-legume cover and one with an early successional grass-forb cover. Chlamydospores of *Glomus fasciculatus* isolated from the feces of these animals produced representative endomycorrhizae with corn under greenhouse conditions.

134. Rothwell, Frederick M.; Trappe, James M. 1979. ***Acaulospora bireticulata* sp. Nov**. Mycotaxon. 8: 471-475.

Acaulospora bireticulata, a new species of the vesicular-arbuscular mycorrhizal fungi, has been isolated from a perimeter soil sample collected at a tree nursery in Kentucky. Endomycorrhizal status was verified in native type specimens obtained from the site as well as in herbaceous plants grown under greenhouse conditions in samples of the perimeter soil. Type material of this fungus has been deposited in the herbarium at Oregon State University.

135. Rothwell, Frederick M.; Victor, Barbara J. 1984. **A new species of endogonaceae: *Glomus botryosellum***. Mycotaxon. 20(1): 163-167.

Glomus botryoides, a new species of the Endogonaceae, was observed in wet-sieved stomach contents of two small malalian mycophagists that were trapped in a wildlife management area in which oak was the predominant plant cover. The chlaymdospore of the new species has a distinct roughened surface and a separable outer wall. It often forms in tight, grape-like clusters from bulbous endings of hyphae.

136. Rothwell, Frederick M.; Vogel, Willis G. 1982. **Mycorrhizae of planted and volunteer vegetation on surface-mined sites**. Gen. Tech. Rep. NE-66. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 12 p.

Records the mycorrhizal status of a number of herbaceous and woody plant species collected on orphan surface-mined sites and adjacent unmined sites, and on planted surface-mined sites in eastern Kentucky and Tennessee.

137. Slick, Bernard M. 1980. **Revegetation for aesthetics**. In: Trees for reclamation. Gen. Tech. Rep. NE-61. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 75-84.

Surface mining is changing the landscape character of forests in the East. Aesthetic aspects of the landscape are considered in the analysis, planning, and design of revegetation strategies. Application of landscape architectural design techniques in the revegetation of surface-mined lands, as well as a knowledge of biological characteristics, enhances the visual character of the mined landscape.

138. Slick, Bernard M.; Curtis, Willie R. 1985. **A guide for the use of organic materials as mulches in reclamation of coal minesoils in the Eastern United States**. Gen. Tech. Rep. NE-98. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 144 p.

Discusses the environmental impacts of coal surface mining, problems associated with disposal of organic wastes, and mulch in relation to erosion, soil properties, and plant growth. Organic materials that have potential use as mulches for revegetating surface-mined lands are identified and described. Selection criteria for organic materials, application methods, equipment, and requirements are explained.

139. Sowa, Edward A.; Davidson, Walter H. 1976. **A new cover crop for spoil banks**. Pennsylvania Farmer. 194(1): 132-133.

Weeping lovegrass may be useful for providing quick, short-term cover while permanent species become established. Fertilizer, particularly nitrogen, enhances the development of weeping lovegrass.

140. Superfesky, Michael J.; Williams, George P., Jr. 1978. **Shear strength of surface-mine spoils meassured by triaxial and direct shear methods**. Gen. Tech. Rep. NE-

39. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 15 p.

Results of measurements of seven surface-mine spoils by the triazial and direct shear methods indicated that the latter is effective in evaluating the shear-strength parameters of surface-mine spoils. The average angle of interval friction determined by direct shear testing was 38.6 degrees; the average value of cohesion determined by direct shear testing of dry materials was 0.100 bar. Soaking specimens immediately before direct shear testing reduced the average angle of internal friction by 8.2 degrees; there was no significant change in cohesion.

141. Thompson, Ralph L.; Vogel, Willis G.; Taylor, David D. 1984. **Vegetation and flora of a coal surface-mined area in Laurel County, Kentucky**. Castanea. 49: 111-126.

A descriptive study was made in 1981 and 1982 of the vegetation and flora on an 18-year-old surface-mined area near Lily in Laurel County, Kentucky. More than 100 woody and herbaceous taxa were planted on about 25 percent of the area in 1965 and 1966. Some of the planted area and most of the unplanted area subsequently were revegetated by natural plant succession. The natural plant community was sampled by the belt transect and quadrat methods; the vascular flora was documented by field reconnaissance; and planted experimental plots were inventoried for surviving species. A Virginia pine-mixed hardwoods community was the major natural vegetation type. The vascular flora comprised 350 taxa from 84 families; 77 of these were nonindigenous taxa. Thirty-seven indigen
ous and 41 nonindigenous species have persisted from the original experimental plantings.

142. Thompson, Ralph L.; Vogel, Willis G.; Wade, Gary L.; Rafaill, Barbara L. 1986. **Development of natural and planted vegetation on surface mines in southeastern Kentucky**. In: New horizons for mined land reclamation: 1986 national meeting of the American Society for Surface Mining and Reclamation; 1986 March 17-20; Jackson, MS. Princeton, WV: American Society for Surface Mining and Reclamation: 145-153.

Describes studies of flora and vegetation on five 17- to 20-year-old surface mines that originally had been partly or entirely planted with herbaceous and woody species. There was a rich flora on these mines as a result of natural secondary succession and artificial plantings. Certain similarities in vegetation were evident at all sites, though there were distinct differences that apparently were to be influenced by site and minesoil characteristics, planted species, and contiguous plant communities. Results of these studies indicate that potentially productive forests are reestablishing on older surface-mined sites in southeastern Kentucky.

143. U.S. Department of Agriculture, Forest Service. 1976. **Do rocks hold answers to environmental ills?** Photo Story No. 33. Upper Darby, PA: U.S. Department of Agriculture, Northeastern Forest Experiment Station. 4 p.

Discusses the need for geological studies before and during mining.

144. U.S. Department of Agriculture, Forest Service. 1977. **Special rain gage**. Photo Story No. 36. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 4 p.

Describes a special rain gage that was designed, tested, and used by researchers with the Northeastern Forest Experiment Station.

145. U.S. Department of Agriculture, Forest Service. 1988. **Plant, soil, and water analysis laboratory**. NE-INF-79-88. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station.

Trained staff using modern equipment efficiently analyzes plant, soil, and water samples from federal, state, or cooperating organizations at reasonable prices.

146. Vogel, Willis G. 1977. **Revegetation of surface-mined lands in the East**. In: Proceedings, 1977 annual meeting of the Society of American Foresters; 1977 October 2-5; Albuquerque, NM. Bethesda, MD: Society of American Foresters: 167-172.

Several species of hardwoods and pine planted 30 years ago have been reasonably successful on spoils in both the Midwest and Appalachian Coal Fields. Especially encouraging is the success of high-value hardwoods such as black walnut, red oak, tulip-poplar, and white pine. Many of the older strip-mined lands are providing excellent wildlife habitat and water-based recreational uses. Most surface mines are being revegetated with herbaceous species to provide quick erosion control. Tree planting has been discouraged largely due to economic, legal, and social pressures. Establishment of both trees and herbaceous cover is feasible, especially by concurrent planting of tree seedlings and nonaggressive herbaceous legumes.

147. Vogel, Willis G. 1979. **Revegetation research on surface-mined land in eastern Kentucky**. In: 4th Kentucky coal refuse disposal and utilization seminar; 1978 June 6-7; Pineville, KY. Lexington, KY: University of Kentucky, Institute for Mining and Minerals Research: 5-15.

Revegetating surface-mined lands in eastern Kentucky received little attention before 1958. Thereafter, revegetation efforts based mostly on experience and standard reforestation practices were only occasionally successful. Research begun by the USDA Forest Service in 1958 and expanded in 1962 helped identify some of the revegetation problems and suggested how to overcome them. Important research was conducted on the suitability of woody and herbaceous species; effects of spoil properties on plants; requirements for fertilizer, lime, mulch,

and seedbed preparation; compatability of trees with herbaceous cover; and microbial associations.

148. Vogel, Willis G. 1980. **Are trees neglected plants for reclaiming surface mines?** Proceedings of the West Virginia Academy of Science. 51(3): 127-138.

Reclaiming surface-mined lands with trees often has been discouraged in recent years because of social, political, legal, and economic reasons. Yet many of the tree plantings made 30 to 50 years ago on surface-mined lands have grown into productive forests. Especially notable is the success of some of the plantings of high-value species such as black walnut, red oak, white ash, tulip-poplar, and white pine. Other plantings are less productive of quality timber, but they provide wildlife habitat, watershed protection, and areas for recreation. Significant in many of the plantings is the overall vegetational development that includes the establishment of volunteer trees and a complex vegetative understory.

149. Vogel, Willis G. 1980. **Revegetating surface-mined lands with herbaceous and woody species together**. In: Trees for reclamation. Gen. Tech. Report NE-61. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station: 117-126.

Herbaceous cover is required for erosion control on surface-mined lands even where forests are to be established. Where planted with trees, herbaceous species usually cause an increase in tree seedling mortality and retard tree growth, particularly in the first few years after planting. Planting trees in existing stands of herbaceous cover usually resulted in poor survival. Planting trees and seeding herbaceous species in alternate strips appear feasible for combination plantings on areas where the appropriate seeding and fertilizing equipment can be used.

150. Vogel, Willis G. 1981. **A guide for revegetating coal minesoils in the eastern United States**. Gen. Tech. Rep. NE-68. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 190 p.

Provides information, recommendations, and guidelines for revegetating land in the Eastern United States that has been disturbed by coal mining. Included are descriptions of major coal-mining regions in the East, and a discussion of minesoil properties and procedures for sampling, testing, and amending minesoils. Plant species that have been used for revegetating surface-mined lands are identified and described. Selection criteria for plant species and methods and requirements for seeding and planting are presented.

151. Vogel, Willis G. 1983. **Ecological considerations in designing and selecting reclamation equipment**. In: Vegetative rehabilitation and equipment workshop, 37th annual report; 1983 February 13-14; Albuquerque, NM. Missoula, MT: U.S. Department of Agriculture, Forest Service, Equipment Development Center: 59-63.

A better understanding of the ecology of the land to be treated is a first step in the selection and design of reclamation equipment. The ecological principles that should be considered in selecting, designing, and modifying such equipment are discussed.

152. Vogel, Willis G. 1984. **Planting and species selection for revegetation of abandoned acid spoils**. In: Proceedings, conference on reclamation of abandoned acid spoils; 1984 September 12-13; Osage Beach, MO. Jefferson City, MO: Missouri Department of Natural Resources, Land Reclamation Commission: 70-83.

The effort needed to revegetate abandoned acid spoils depends on the degree of acidity, amount and kind of existing vegetation, and land-use objective. It may entail no more than planting tree and shrub seedlings in unvegetated zones or include earth moving and grading, topsoiling, applying soil amendments, and planting herbaceous and woody species. Treatment could be minimal on sites not contributing to off-site environmental damage and where spoils will support the growth of more acid-tolerant species. Several pine and birch species, black locust, European alder, autumn olive, and bristly locust are woody species to consider for extremely acid spoils. Weeping lovegrass, Bermuda grass, deertongue, broomsedge, flatpea, and Japanese fleeceflower are prospective herbaceous species.

153. Vogel, Willis G. 1987. **A manual for training reclamation inspectors in the fundamentals of soils and revegetation**. Washington, DC: U.S. Department of the Interior, Office of Surface Mining and Enforcement and U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 178 p.

This handbook can be used in the training of surface mining and reclamation inspectors. It provides guidance in understanding and adapting principles and practices of soil and plant sciences appropriate to overburden and soil removal, replacement, testing, and treatment; selecting and using species for various conditions and land uses; and evaluating revegetation success.

154. Vogel, Willis G.; Curtis, Willie R. 1978. **Reclamation research on coal surface-mined lands in the humid East**. In: Reclamation of drastically disturbed lands. Madison, WI: American Society of Agronomy: 379-397.

Presents a general overview of the results and application of some of the research on surface-mine reclamation conducted on coal lands in the Eastern United States. Research activities are discussed with respect to revegetation, soil science, hydrology, geology, wildlife management, and engineering.

155. Vogel, Willis G.; Gray, Brent. 1987. **Will trees survive on topsoiled surface mines?** In: Proceedings, 1987 national symposium on mining, hydrology, sedimentology, and reclamation; 1987 December 7-11; Springfield, IL. Publ. UKY BU145. Lexington, KY: University of Kentucky: 301-305.

Trees planted on surface mines reclaimed by post-law requirements often fail to survive. This problem occurs with the replacement and grading of overburden and especially topsoiling materials. To investigate this situation, survival of pine seedlings planted in spring 1982 was compared on topsoiled and non-topsoiled surface-mine spoil in western Kentucky. In spring 1983, pine seedling survival was 89 percent on the topsoiled area and 48 percent on the spoil. By October 1983, survival of pine had dropped to 4 percent on the topsoiled area and 36 percent on the spoil. The topsoiled area supported a herbaceous cover averaging about 50 percent versus about 70 percent on the spoil. The high mortality of pine trees on the topsoil seemingly was related to a lack of soil moisture during the extremely dry late summer of 1983.

156. Vogel, Willis G.; Richards, T. 1985. **Survival of northern red oak and white oak seedlings planted in tall fescue and black locust-crownvetch covers**. In: Pope, P. E., ed. Better reclamation with trees: proceedings of the 4th annual conference; 1984 June 7-8; Owensboro, KY. West Lafayette, IN: Purdue University: 33-41.

Northern red oak and white oak 1-0 seedlings were planted in herbaceous cover dominated by Ky-31 tall fescue and in black locust stands with an understory of crownvetch. Planting sites in both cover types were selected on north and south aspects on surface-mined land in Breathitt County, Kentucky. The sites had been vegetated for about 10 years. No herbicide or other site preparation was used to control existing vegetation. Survival of first-year seedlings ranged from 51 to 95 percent. Survival of northern red oak was significantly greater under black locust than in fescue. White oak survival was greater on north than on south slopes in both cover types, but survival of northern red oak under black locust was greater on the south slope. Crownvetch growing under black locust overtopped and smothered some tree seedlings, particularly the smaller white oak.

157. Vogel, Willis G.; Rothwell, Frederick M. 1986. **Bark mulch aids establishment of black walnut planted on western Kentucky mine spoils**. In: Kolar, Clay A., ed. Better reclamation with trees: proceedings of the 5th annual conference; 1985 June 5-7; Carbondale, IL. [Place of publication unknown]: [Publisher name unknown]: 104-110.

Mulching with hardwood bark greatly increased survival of black walnut seedlings planted on sandy loam mine spoil in western Kentucky. Four methods of planting the seedlings were compared: planting bar, mattock, 8-inch auger hole backfilled with spoil, and auger hole backfilled with topsoil. Half of the seedlings in each treatment were mulched by placing a bushel of shredded hardwood bark around each seedling when it was planted. A dense ground cover (about 90 percent) predominantly of sericea lespedeza had become established by the fourth year after planting. After 7 years, survival of black walnut trees averaged 58 percent for mulched trees and 17 percent for unmulched ones. There were small differences in survival among the methods of planting.

158. Vogel, Willis G.; Rothwell, Frederick M. 1988. **Mushroom compost and papermill sludge influence development of vegetation and endomycorrhizae on acid coal-mine spoils.** In: Mine drainage and surface reclamation, proceedings of conference sponsored by American Society for Surface Mining and Reclamation, Bureau of Mines, and Office of Surface Mining Reclamation and Enforcement; 1988 April 19-21; Pittsburgh, PA. Inf. Circ. 9184. Washington, DC: U.S. Department of the Interior, Bureau of Mines: 206-213.

Several rates of spent mushroom compost and papermill sludge were evaluated as amendments in revegetating abandoned acid mine spoils (pH 3 to 4.1). Results showed that mushroom compost and papermill sludge are useful materials to aid revegetation of acid spoils, though the long-term effect of mycorrhizal inhibition in compost-treated spoils could not be predicted. The estimated cost of applying these organic materials was about 2.5 times that of applying appropriate rates of lime, mineral fertilizer, and mulch, but yields of vegetation also were 2 to 3 times greater from the compost and sludge amendments.

159. Wade, Gary L. 1986. **Forest topsoil seed banks for introducing native species in eastern surface-mine reclamation**. In: New horizons for mined land reclamation: 1986 national meeting of the American Society for Surface Mining and Reclamation; 1986 March 17-20; Jackson, MS. Princeton, WV: American Society for Surface Mining and Reclamation: 155-164.

Three pioneer communities, a mix of commonly used reclamation species, a community from a forest soil seedbank, and a mixed community of reclamation species plus seedbank species were established on surface-mine spoils in microplots. A total of 84 taxa originated from the soil seedbank, including five tree species. Adding the reclamation species to the seedbank soil resulted in significantly fewer established native species, including tree seedlings in the resulting community; many native species were stunted or phenologically delayed. The seedbank community produced more aboveground biomass and sequestered more N, P, K, Ca, and Mg in vegetation than in the other two communities.

160. Wade, Gary L. 1987. **Forest seed banks for introducing native species (Tennessee, Kentucky).** Restoration and Management Notes. 5(1): 29-30.

Emphasizes the use of forest topsoils as a propagule source rather than as a growth medium. Topsoils also introduce soil microflora and fauna that have important rioles in decomposition, nutrient cycling, formation of soil organic matter, and soil formation generally. Seedbank species also may serve as an instrument for ecosystem recovery after future disturbances.

161. Wade, Gary L. 1988. **Effective mining and reclamation as ecosystem construction**. In: Environmental workshop—1988 proceedings; 1988 September; Darwin, Australia. Dickson, Australia: Australian Mining Industry Council: 175-190.

Describes how the challenge of converting mined lands to productive landscape units can best be met by approaching reclamation as a problem associated with ecosystem construction. Characteristics that need to be considered in ecosystem construction are discussed.

162. Wade, Gary L. 1989. **Grass competition and establishment of native species from forest soil seed banks**. Landscape and Urban Planning. 17: 135-149.

Three pioneer plant communities, a reclamation mix of tall fescue, weeping lovegrass, ryegrass, and sericea lespedeza; a native species community derived from a forest topsoil seedbank; and a combination of native species plus the reclamation mix were established on a thin layer of topsoil over mine spoils in microplots. The seedbank produced 84 taxa, including five tree species, seven shrubs or woody vines, 14 grasses, and 53 forbs identifiable at least to genus. The seedbank treatment produced the greatest aboveground biomass. Adding seed of reclamation species to the seedbank resulted in a community with less total biomass, less total biomass in native species, and fewer established native species with lower populations and biomass than the native-species community without reclamation species.

163. Wade, Gary L.; Crews, Jerry T.; Vogel, Willis G. 1986. **Development and productivity of forest plantations on a surface mine in southeastern Kentucky**. In: Kolar, Clay A., ed. Better reclamation with trees: proceedings of the 5th annual conference; 1985 June 5-7; Carbondale, IL. [Place of publication unknown]: [Publisher name unknown]: 184-193.

Pine and mixed hardwoods plantations established in 1965 on a north-facing slope on a surface-mine reclamation demonstration area near Middlesboro, Kentucky, were evaluated in 1983-85. Site indices were calculated from age-height curves for loblolly pine, Virginia pine, yellow-poplar, American sycamore, red maple, northern red oak, white oak, and black oak. Site indices for northern red oak and yellow-poplar also were calculated in second-growth forest on the same slope above and below the mined site. Site indices on the mined and planted areas compare favorably with the unlined area. There were no consistent differences in site indices between bench and outslope positions.

164. Wade, Gary L.; Halverson, Howard G. 1988. **Soil development under 22-year-old mixed hardwood, pine, and black locust plantations on a surface mine**. In: Mine drainage and surface mine reclamation: proceedings of a conference sponsored by American Society for Surface Mining and Reclamation, Bureau of Mines, and Office of Surface Mining Reclamation and Enforcement; 1988 April 19-21; Pittsburgh, PA. Inf. Circ. 9184. Washington, DC: U.S. Department of the Interior, Bureau of Mines: 54-62.

A study of soil development under three forest vegetation types showed development of O, A, and B horizons after 22 years. O horizon thickness was greatest under pine (3.5 cm) and least under mixed hardwoods (2.4 cm); concentrations of N, P, Ca, Mg, Cu. Zn, Si, and Ni had significant differences attributable to vegetation type. A horizon development was variable with a mean thickness of 2.3 cm. There were significant differences between the A and B horizons in organic-matter content, conductivity, exchangeable acidity, and concentrations of available N, P, K, Ca, Mg, Mn, Cu, Zn, B, Na, Pb, Ti, and Cr.

165. Wade, Gary L.; Halverson, Howard G. 1990. **Forest resource potential of reclaimed mined lands**. In: Bagby, Jane W., ed. Environment in Appalachia: proceedings of the 1989 conference on Appalachia; 1989 November 2-3; Lexington, KY. Lexington, KY: University of Kentucky, Appalachian Center: 55-61.

Describes the characteristics that make a forest ecosystem productive, reports results from studies of rapid development of forest soil from mine spoils, and provides examples of forest productivity on mined lands ranging from mediocre to good. Reasons for past successes and requirements for future successes in that reclamation of mined lands are discussed.

166. Wade, Gary L.; Thompson, Ralph L. 1990. **Establishment of native plant species from forest topsoil seedbanks on a borrow area in Kentucky**. In: Skousen, J.; Sencindiver, J.; Samuel, D., eds. Proceedings of the 1990 mining and reclamation conference and exhibition. Vol. II; 1990 April 23-26; Charleston, WV. Morgantown, WV: West Virginia University: 451-460.

The seedbanks in forest topsoils were used to introduce native species to an unreclaimed, xeric borrow area in eastern Kentucky. Results are reported for the following eight treatments: (1) 1 cm topsoil + mulch, (2) 1 cm topsoil tilled into the substrate + mulch, (3) 2 cm topsoil + mulch, (4) 1 cm topsoil without mulch, (5) 4 cm topsoil in strips covering 25 percent of the area + mulch, (6) 1 cm topsoil + a grass-legume reclamation mix + mulch, (7) reclamation mix + mulch without topsoil, and (8) mulch without topsoil or reclamation mix. The seedbank produced 90 species from 34 families including seven tree species, seven shrubs, 16 graminoids, and 50 forbs. Forest topsoil use introduced 57 native or naturalized species during the first growing season and 82 species were present during the second growing season. Average ground cover of native species totaled only about 5 percent after 10 weeks of the first growing season. Wheat and timothy seed contained in the hay mulch increased mean ground cover to more than 70 percent.

167. Wade, Gary L.; Thompson, Ralph L.; Vogel, Willis G. 1985. **Success of trees and shrubs in an 18-year-old planting on mine spoil.** Res. Pap. NE-567. Broomall, PA:

U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 10 p.

Plantings of 25 shrub and 25 tree species on a surface mine were evaluated after 18 years and results were compared to a 4-year evaluation. Pin oak, sweet birch, European white birch, Austrian pine, and bur oak show promise for wood products. Several other species are useful as soil builders and site stabilizers and for wildlife habitat. Results suggest that mortality of some species during the past 14 years is related primarily to intraspecific and interspecific competition rather than spoil characteristics.

168. Wade, Gary L.; Vogel, Willis G. 1988. **Surface-mined lands. Hope for future forests?** NE-INF-77-88. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 12 p.

Surface mining begins with a great disruption of the environment. Trees and plants are uprooted and soil and rocks are displaced or shattered by blasting. But as destruction often carries the germ of creation, the process of surface mining may lead to conditions that encourage forest productivity over the long run. This hopeful outlook is the result of a demonstration conducted in Fonde, Kentucky, over a period of about 20 years.

169. Weisenfluh, G. A.; Ferm, J. C.; Bailey, A.; Despard, T. L.; Vogel, W. G. 1981. **A study of geologic factors influencing reclamation of federal coal bearing lands in northern Alabama.** In: Proceedings, 1981 symposium on surface mining hydrology, sedimentology, and reclamation symposium; 1981 December 7-11; Lexington, KY. Lexington, KY: University of Kentucky: 151-156.

An investigation of the reclamation properties of potential overburden materials of surface mineable coal seams underlying federal lands in the Warrior Coal Field of Alabama was conducted in three parts. These were: (1) description of the geologic setting of the federal lands; (2) analyses to determine chemical and mineralogical properties of overburden rocks with greenhouse studies to determine the ability of each rock type to support plant growth; and (3) a statistical analysis of the first and second parts. Results of these studies showed that: (1) the rocks in this region are not acid but mostly alkaline; (2) treatment with nitrogen and phosphorus resulted in the best plant growth; and (3) rock materials most suited for revegetation are fine-grained, smooth-textured shales and “rooted” rock.

170. Williams, George P., Jr. 1979. **Wood chips for dust control on surface-mine haul roads**. Res. Note NE-277. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 16 p.

On a coal haul spur road where water sprinkling was the primary method of dust control, the duration of control was increased tenfold by covering the road surface with a layer of wood chips. The blanket prevented existing dust-size particles from being kicked up and swept into plumes by passing traffic, insulated the road surface against evaporation, and protected it from the pounding and abrasion of truck tires.

171. Willis, Raymond B. 1980. **Reduction column for automated determination of nitrate and nitrite in water**. Analytical Chemistry. 52(8): 1376-1377.

A method for determining nitrate plus nitrite was developed using wire reduction made of silver-cadmium inserted in Teflon tubing. This wire is stronger, less expensive, and more readily available than pure cadmium wire.

172. Willis, Raymond B.; Gentry, Claude E. 1987. **Automated method for determining nitrate and nitrite in water and soil extracts**. Communications in Soil Science Plant Analysis. 18(6): 625-636.

Describes an AutoAnalyzer method for measuring nitrate plus nitrite in 13 commonly used soil-extraction solutions. The AutoAnalyzer usually is equipped with a column containing cadmium chips. In this study, the column was replaced with a cadmium-silver wire inserted in plastic tubing. The advantages are: (1) there is no compaction of cadmium chips; (2) the need to debubble the sample stream before it enters the reductor is eliminated; (3) the dead volume is decreased; and (4) the copper sulfate treatment is eliminated except for one treatment the first time the wire is used.

173. Willis, Raymond B.; Mullins, Gregory L. 1983. **Automated analysis for water alkalinity**. Analytical Chemistry. 55(7): 1173-1175.

The automated method for determining alkalinity has been modified to enable measurement of concentrations of $CaCO_3$ in the range of 10 to 500 mg/l. Previous automated methods did not permit measurements below 100 mg/l. Results obtained by automated methods using two different instruments and the manual titration method are compared.

174. Wong, B. L.; Melhuish, J. H., Jr.; McQuattie, C. J. 1987. **The role of mycorrhizae in the accumulation of trace metals under different pH concentrations in conifer tree organs and tissues.** In: National acid precipitation assessment program, terrestrial effects task group (V) peer review; 1987 March 8-13; Atlanta, GA [Place of publication unknown]: [Publisher name unknown]: B-3: 220-225.

Acid deposition may affect forest trees through soil-mediated responses by an acceleration of soil acidification and/or enhancement of solubility and mobility of metal ions. These ions may be present naturally in soils or deposited directly onto the soil from some form of atmospheric pollution. Because the concentration of some heavy (or trace) metals may be increasing in the forest ecosystem, information is needed on the effects of trace metals on trees and beneficial microorganisms such as mycorrhizal fungi that are necessary for the growth of forest trees.

175. Wong, B. L.; Melhuish, J. H.; McQuattie, C. 1988. **The role of mycorrhizae in the accumulation of trace metals under different pH concentrations in loblolly pine**. In: Forest response program annual meeting; 1988 February 22-26; Corpus Christi, TX. Raleigh, NC: North Carolina State University, Atmospheric Impacts Research Program: 70-78.

As atmospheric deposition and soil acidity increase, many heavy (or trace) metals become increasingly available in soils that may affect the growth and physiological functions of mycorrhizal fungi and the associated plant. This study was initiated to evaluate and characterize the role of the loblolly pine mycorrhizal association in trace metal uptake, metal accumulation within the plant and fungus, and resulting effects on seedling growth when exposed to a variety of metals at different concentrations and pH levels.

176. Woods, Frank W.; Becker, Charles W.; Curtis, Willie. 1986. **Haul roads: post-mining management problems**. In: New horizons for mined land reclamation: 1986 national meeting of the American Society for Surface Mining and Reclamation; 1986 March 17-20; Jackson, MS. Princeton, WV: American Society for Surface Mining and Reclamation: 215-219.

Monitoring stations were installed in three small watersheds in the Cumberland Mountains and three in the Cumberland Plateau of east Tennessee to evaluate the effects of surface mining on water quality. Each set had a recently mined, old mined, and unlined watershed. Streamflow and concentration levels for five water-quality parameters, collected every 4 weeks from 1981 through 1984, were evaluated. There were differences in water quality between mined and unlined watersheds. The mined watersheds had generally higher levels of minerals and greater turbidity.

177. Woods, Frank W.; Becker, Charles W.; Curtis, Willie. 1986. **Recovery of water quality after strip mining**. Tennessee Farm and Home Science. 140:10-13.

Surface mining can produce high levels of sediment and dissolved minerals in streams and other waters. Poor reclamation and haul roads also can reduce water quality and prolong the period of recovery following mining. This study was initiated to determine the rate at which the water quality of streams in watersheds subject to surface-mining runoff returns to normal.

Acknowledgment

I thank Linda Plaugher for assistance in preparing this manuscript and Sheryl Dew for helping assemble the materials used in this bibliography.

Index by Subject

Acid spoils 124, 152, 169

Aesthetic considerations 137

Anthracite surface mines 46, 74

Bird life 1

Bituminous surface mines 37, 44, 100

Ecology 27, 28, 29, 36, 45, 99, 151, 159, 161, 162, 165, 166

Education (of inspectors) 3, 43, 126, 150, 153

Flora (excluding trees) 27, 28, 29, 30, 31, 36, 37, 47, 54, 110, 117, 121, 127, 139, 141, 142, 149, 159, 160, 162, 166

Geological properties 77, 143, 169

Land management 3, 21, 27, 44, 45, 52, 102, 103, 119, 120, 126, 142, 146, 147, 152, 160

Microbial properties
- general 7, 131, 135
- Ecto (endo) mycorrhizal formations 13, 15, 16, 17, 18, 132, 133, 134, 136, 158, 174, 175
- Fungal metabolic properties 108, 113, 114, 129, 130, 133
- *Pisolithus tinctorius* 112

Mulches 36, 92, 93, 122, 125, 138, 157, 158, 170

Overburden (spoil)
- Characteristics 59, 78, 102, 140, 164, 168
- Placement 53, 102, 140, 155, 176
- Properties 51, 78, 140
- Sealants 32, 90

Photography 96, 97

Research needs 41, 148, 154

Soils
- Analysis 59, 145
- Characteristics 59, 155, 165
- Compaction 31, 176
- Disturbance 155, 168
- Erosion control 102, 176
- Geotechnical properties 164
- Nitrogen fixation 5
- Physical properties 102, 155
- pH 4, 51, 67
- Stones (stony) 2

Trees
- Forestry practices (reforestration) 19, 51, 52, 62, 63, 69, 71, 72, 106, 107, 109, 115, 116, 148, 168
- Improvements/growth 25, 62, 63, 72, 109, 115, 167
- Plantations 106, 107, 163
- Species
  - Alder 118
  - Ash (white and green) 117
  - Birch 48
  - Black locust/walnut 6, 156, 157, 164
  - Conifers (pine, spruce) 14, 22, 49, 57, 58, 61, 64, 70, 74, 76, 104, 105, 117, 118, 123, 128, 141, 155, 164
  - Oak 20, 22, 66, 68, 156
  - *Paulownia tomentosa* 10, 11, 12, 111
  - Sweetgum 26
  - Tuliptree 107, 148
  - Yellow/hybrid poplar 50, 56, 60, 65, 73, 75
- Survival 21, 72, 149
- Volume 55

Water Quality
- Alkalinity/acidity (water chemistry) 9, 79, 80, 81, 82, 83, 84, 85, 86, 87, 91, 94, 98, 100, 101, 145, 171, 172,
- Floods 89
- Hydrologic processes 19, 23, 35, 37, 39, 40, 86, 89
- Impoundments 42, 53, 88
- Sampling techniques (rain gages) 33, 42, 95, 144, 171, 172
- Sedimentation 34, 37, 44, 99, 125, 177
- Streamflow and peakflow 23, 24, 34, 37
- Surface mining effects 9, 37, 39, 40, 42, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 91, 98, 101, 177

Wildlife 127

Crews, Jerry T., comp. 1999. **Bibliography of surface-mine reclamation research: 1976-1993.** Gen. Tech. Rep. NE-262. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 25 p.

Contains citations for 177 articles and publications that describe research on or related to reclamation of surface-mined lands conducted from 1976 through 1993 by scientists with the Northeastern Forest Experiment Station and cooperating organizations. A subject index is included.

Keywords: strip mines; mine soil; coal-mine reclamation; revegetation; acid mine drainage; mine spoils.

Headquarters of the Northeastern Research Station is in Radnor, Pennsylvania. Field laboratories are maintained at:

Amherst, Massachusetts, in cooperation with the University of Massachusetts

Burlington, Vermont, in cooperation with the University of Vermont

Delaware, Ohio

Durham, New Hampshire, in cooperation with the University of New Hampshire

Hamden, Connecticut, in cooperation with Yale University

Morgantown, West Virginia, in cooperation with West Virginia University

Parsons, West Virginia

Princeton, West Virginia

Syracuse, New York, in cooperation with the State University of New York, College of Environmental Sciences and Forestry at Syracuse University

Warren, Pennsylvania

"Caring for the Land and Serving People Through Research"