SELECTING TOPSOIL SUBSTITUTES FOR FORESTRY MINE SOILS[1]

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Abstract The Forestry Reclamation Approach is a five-step system for reclaiming mined lands to forests. Step 1 of the FRA involves creating a suitable rooting medium for good tree growth using topsoil, weathered sandstone and/or the best available material. Several types of overburden types can be selected to place on the surface as growth media. These spoil types include weathered brown sandstone and unweathered rock materials including sandstones, siltstones, shales, and mixtures of these materials. When sufficient topsoil is not salvageable, reclamation scientists often recommend that, when available, weathered sandstone should be considered as the 'best available' topsoil substitute material. Here, we review the scientific evidence that supports such recommendations.

Several studies have shown that ***tree survival*** was not significantly different among spoil types. Weathered brown sandstone, unweathered gray sandstone, siltstone and shale materials all produced good tree survival (>70%) when compaction and competitive ground covers were reduced. However, ***growth*** for most trees (as measured by height, diameter, and volume) was usually significantly greater in weathered brown materials than in unweathered sandstones, siltstones, shales, and mixed spoils. At one site in West Virginia five years after planting, a 10-fold difference in tree volume was found between these two spoil types. Similar results have been found with other studies across Appalachian surface mines.

Based on the results of studies summarized herein, the use of weathered brown sandstone is generally recommended, along with topsoil materials when available, to be placed on the surface on sites where hardwood tree species are being planted for forestry post-mining land uses. Weathered brown sandstone spoil materials have a pH, soluble salt content, fine earth content well suited for trees, and sufficient nutrient supplying and water holding capacity that results in superior tree growth compared to other spoil types. The brown sandstone material more closely resembles the native forest soil than the unweathered gray materials.

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[1] Paper was presented at the 2011 National Meeting of the American Society of Mining and Reclamation, Bismarck, ND, ***Reclamation: Sciences Leading to Success***, June 11-16, 2011. R.I. Barnhisel (Ed.) Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

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Proceedings America Society of Mining and Reclamation, 2011 pp 591-609
DOI: 10.21000/JASMR11010591
http://dx.doi.org/10.21000/JASMR11010591

Introduction

The United States Department of Interior's Office of Surface Mining Reclamation and Enforcement (OSM) and the state regulatory authorities in the Appalachian Region have embarked on a campaign to encourage mine reclamation practices that: (1) plant more high-value hardwood trees on reclaimed coal mined lands in Appalachia, (2) increase the survival rates and growth rates of planted trees, and (3) expedite the establishment of forest habitat and ecological benefits through natural forest succession (ARRI, 2011). Drawing on the recommendations generated by surface mine reclamation research over the past eighty years, OSM and state regulatory authorities developed and are advocating a five-step system to reforest coal mined land called the Forestry Reclamation Approach (FRA). The steps are:

(1) create a suitable rooting medium for good tree growth that is no less than 1.2 m deep and comprised of topsoil, weathered sandstone, and/or the best available material;

(2) loosely grade the topsoil or topsoil substitutes placed on the surface to create a non-compacted growth medium;

(3) use native and non-competitive ground covers that are compatible with growing trees;

(4) plant two types of trees – early succession species for wildlife and soil stability, and commercially valuable crop trees; and,

(5) use proper tree planting techniques (Burger et al., 2005).

Forest Reclamation Advisories have been written on various aspects of the Forest Reclamation Approach such as a description of the approach (No. 2), Low Compaction Grading Techniques (No. 3), Loosening Compacted Soils (No. 4), Natural Succession (No. 5), Tree-Compatible Ground Covers (No. 6), and Tree Planting Techniques (No. 7). These advisories are available at http://arri.osmre.gov/FRA/FRA.shtm

This paper gives a background and summary of work for the first step in the FRA: "Create a suitable rooting medium for good tree growth that is no less than 1.2 m deep and comprised of topsoil, weathered sandstone and/or the best available material."

The selection and placement of a suitable rooting medium is critical for good survival and growth of trees in surface mine reclamation, and greatly enhances and accelerates the development of a diverse forest ecosystem. When native topsoil is not abundant, weathered sandstone or a mix of weathered sandstone and unweathered rock materials is often advocated by reclamation scientists as the best topsoil substitute material, when available. Here, we describe scientific background for that designation.

Early Reforestation of Surface Mines

Reforestation of surface mines was an important practice during early days of surface mining in the US (Brown, 1962). From the 1930s to 1970s, reforestation efforts showed good success and some of the most favorable forest sites with the highest tree growth were old unreclaimed surface mines (Potter et al., 1955; Zeleznik and Skousen, 1996) (Fig. 1-3). This good tree growth was attributed to the random placement of weathered overburden at the surface (overburden selection and placement were not planned or regulated), little or no surface grading to compact the soils, and little or no seeding of grass for revegetation (Ashby, 2006; Gorman et al., 2001). Because the older surface mines were smaller and often disturbed only near-surface rock, weathered overburden materials often comprised the majority of overburden and was placed on the surface loosely, with minimal or no grading. Planted trees did exceptionally well

Figure 1. Left Picture - Cottonwood established naturally among planted shortleaf pine on ungraded, mixed spoil, then planted with hardwoods. The planting was established in 1939 and this USDA Forest Service photo was taken in May 1946 (7 yrs old). Middle Picture - The same shortleaf pine stand in April 1964 (25 yrs old). Right picture is the same shortleaf pine stand at age 30 (photo taken in 1969). Most of the pines are dead or dying and planted and unplanted hardwoods are taking over the canopy (Ashby, 2006).

Figure 2. Red oak stand planted in 1938. This picture was taken in February 1977 at age 39. This stand averaged 33 m (108 ft) tall at age 55 (Ashby, 2006), which demonstrates the productivity of the site.

Figure 3. White oak trees at age 40 on ungraded spoil banks. Average height at age 55 was 26 m (85 ft). This picture was taken in February 1979. Mosaics of single-species patches have given good growth (Ashby, 2006).

in these loose, weathered rock materials, and recruitment of adjacent native trees onto the disturbed site was rapid (Skousen et al., 1994, 2006; Tryon, 1952), which produced a diverse forest after 10 to 20 years.

Reforestation After SMCRA

With the passage of the federal Surface Mining Control and Reclamation Act in 1977, much of the land was reclaimed to grasslands, which when left unmanaged often turned into an invasive shrub-dominated landscape with little commercial value, utility, or biological productivity (Fig. 4). Reforestation efforts in post-SMCRA reclaimed areas have generally resulted in poor seedling survival and slow growth because trees were planted into compacted mine soils and a heavy herbaceous ground cover (Chaney et al., 1995; Skousen et al., 2009; Torbert and Burger, 2000) (Fig. 5). Many operators and regulators interpreted SMCRA reclamation rules to require these compacting and seeding practices which resulted in reforestation failures (Andersen et al., 1989; Plass, 1982).

The selection of a suitable rooting medium for trees was not perceived as a major problem because operators and regulators viewed compaction of the surface mine soil and competition from ground cover as the primary obstacles to successful reforestation on mined lands. Operators and practitioners were less concerned about the mineralogy and properties of the "topsoil" rooting medium since grasses and legumes and even trees seemed to grow well in a variety of spoil types as long as soil compaction and ground cover competition were reduced. Only later was it determined that tree growth was quite variable on sites with differing mine soils (Andrews et al., 1992; Ashby et al., 1984; Daniels and Amos, 1984; Johnson and Skousen, 1995; Rodrigue and Burger, 2004; Torbert et al., 1990; Zeleznik and Skousen, 1996). Recent research has indeed verified tremendous differences in tree growth in different spoil types placed at the surface as rooting media.

Spoils into Soils

The development of broken rock materials into a mine soil is a process that is influenced by reclamation practices. The potentially available overburden rock types that may be placed at the surface as rooting media are weathered and unweathered sandstones, siltstones, and shales. These different rock types when left on the surface will weather and transform into a variety of mine soil materials, each developing vastly different physical and chemical properties over time

(Sencindiver and Ammons, 2000). This differential weathering among rock types influences the rate of soil genesis and the future productivity potential of the soil (Gorman et al., 2001; Haering et al., 1993; Johnson and Skousen, 1995; Torbert et al., 1988).

Figure 4. Reclamation to grasslands with compacted soils and heavy herbaceous cover under current SMCRA guidelines (and subsequently unmanaged by the landowner) rapidly evolve into an undesirable shrub land of autumn olive and black locust. The FRA's 5-step procedure will largely eliminate the development of such post-mining lands in "arrested succession" (Groninger et al., 2007).

Many forest soils in Appalachia are thin and rocky. Most Appalachian mine soils are also rocky with high coarse fragment content and a low percentage of fine earth materials (<2mm in particle size). Weathered brown sandstone materials (Fig. 6) tend to have a greater percentage of fine sized particles and also weather more quickly into a soil-like material than unweathered gray sandstone (Angel et al., 2008; Emerson et al., 2009; Torbert et al. 1990). Weathered sandstones usually produce soils with textures such as sandy loams that are well-suited to tree growth. Siltstone and shale materials also weather rapidly but their resulting textures have more silt and

Figure 5. Trees planted into compacted soils and heavy groundcover may survive, but cannot be expected to grow well. This site, composed of unweathered rock materials, maintains a high soil pH, which promotes vigorous grass growth.

Figure 6. Weathered brown sandstone can be found immediately below the soil and it will often extend to about 30 feet below the surface, although that depth will vary. Weathered brown sandstone can usually be identified and discriminated visually from the unweathered rock below. Under the brown sandstone material will be found the unweathered rocks that typically comprise the majority of overburden volume in most modern mine sites. The brown sandstone has been found to be a better material to place on the surface for forestry post-mining land uses.

clay, which can become dense due to compaction or settling and may reduce water and air movement (Casselman et al., 2006, Burger et al., 2007).

Several researchers found weathered brown sandstone to have a lower pH (from 4.5 to 6.0) than unweathered gray sandstone, siltstone and shale materials (from 6.5 to 8.5). This lower pH is more conducive to tree growth (Torbert and Burger, 2000). High soluble salts is also detrimental to good tree growth and these salt concentrations increase with greater shale and siltstone contents in fresh mine soils (Torbert et al., 1990).

Although most weathered sandstones are favorable for use as topsoil substitutes, the tremendous variety of soil and rock conditions that occur throughout the Appalachians dictate that this may not always be the case. Materials that weather from pyritic sandstones, for example, have been studied to determine their suitability for reforestation. Such materials may cause degradation of water quality if used on the surface (Isabell 2001). Studies to date indicate, however, that the vast majority of weathered sandstone materials found on Appalachian coal surface mines are favorable for native Appalachian forest tree growth.

Tree Survival in Different Spoil Types

Tree survival has been studied on a number of coal-mined sites in the Appalachian Coal Region. In areas where the problems commonly associated with reforestation have been ameliorated (compaction, ground cover competition, quality of seedlings and planting techniques), studies have shown little difference in tree ***survival*** across a wide range of spoil types (Angel et al., 2008; Casselman et al., 2006; Emerson et al., 2009). Reports of 80 to 90% survival are common after the first year, which gradually declines to 60 to 70% survival after three to five years after planting trees into weathered brown and unweathered gray sandstone. For example, across a variety of hardwood trees, survival was 86% on unweathered gray sandstone and 74% on weathered brown sandstone after three years (Emerson et al., 2009). After five years on the same site, tree survival declined to 68% on gray and 67% on brown (DeLong, 2010). Trees survive well on either type of spoil when planted properly into uncompacted sites with little ground cover.

Tree Growth in Different Spoil Types

Recent studies, however, have documented much greater ***growth*** of hardwood trees in weathered brown materials than in unweathered gray sandstone, siltstone, shale, and mixtures of these materials (Fig. 7-10). The ability of trees to grow well is important because it demonstrates land capability, which should be returned to pre-mining levels. Figure 11 shows that as tree height increases, the value of the trees and forest increase exponentially on good mine soils compared to poor mine soils. Figure 12 illustrates the potential difference in volume growth when trees are grown in better quality mine soils. In a West Virginia study, 11 hardwood trees showed large differences in volume (height x diameter^2) between brown and gray sandstone materials. After the third growing season (Emerson et al., 2009), volume was 218 cm^3 on weathered brown materials and 44 cm^3 on unweathered gray materials, a five-fold difference in volume! After five years (DeLong, 2010), the results were even more dramatic: 1840 cm^3 on weathered brown materials and 178 cm^3 on gray materials, a ten-fold difference!

Figure 7. Weathered brown sandstone in West Virginia originally dumped in piles and leveled with one pass has weathered after two years into a mine soil with good tree growth and with good colonization of native plants.

Figure 8. Unweathered gray sandstone in West Virginia originally dumped in piles and graded with one pass shows some weathering into smaller particles after two years, and generally poor tree growth and poor colonization by native plants compared to weathered brown sandstone soil materials.

Similarly, at the Bent Mountain site in Kentucky (Angel et al., 2008), brown spoil materials produced significantly greater tree height, diameter and tree volume than gray spoil materials. After the third year, average tree volume for brown was 235 cm^3 and 84 cm^3 for gray, a four-fold difference.

The better growth in weathered brown sandstone overburden is largely attributed to a slightly acid pH, low soluble salts, good drainage and aeration, and better water retention compared to most unweathered rock materials; however, the unweathered rocks generally contain more base cations such as Ca, Mg, and K, as well as S. After 10 to 20 years when trees close canopy and fully occupy the rooting zone, they have greater demand for soil nutrients. Additional nutrients provided by mixing some unweathered rock materials with the weathered brown sandstone increases base cation levels that are especially important to species such as tulip poplar, ash,

Figure 9. Tree growth and herbaceous plant cover in weathered brown sandstone at the same site in Fig. 7 planted with native hardwoods after six years of growth.

maples, and some oak species. In a survey of 14 pre-law mined sites with mixed hardwood forests ranging from 35 to 56 years old, Rodrigue and Burger (2004) showed that long term forest productivity was significantly correlated with base saturation. From a replicated study on post-law mine sites at the Powell River Project in Wise Co., VA, Burger and Fannon (2009) reported that growth of 15-year-old tulip poplar, red oak and white oak were positively correlated with cation exchange capacity and extractable calcium. Therefore, a collection of different studies in the Appalachian region shows that native topsoil provides soil flora and fauna, seed pools, organic matter, and needed N and P; weathered sandstone provides an agreeable pH and salt content, good aeration and drainage and good water retention and availability; and unweathered rock materials provide a long term source of essential base cations such as Ca, Mg and K. A mix of these materials may optimize the quality of mine soils for restoring forest productivity for native species.

Figure 10. Tree growth and herbaceous cover on unweathered gray sandstone at the same site as Fig. 8 planted with native hardwoods after six years of growth.

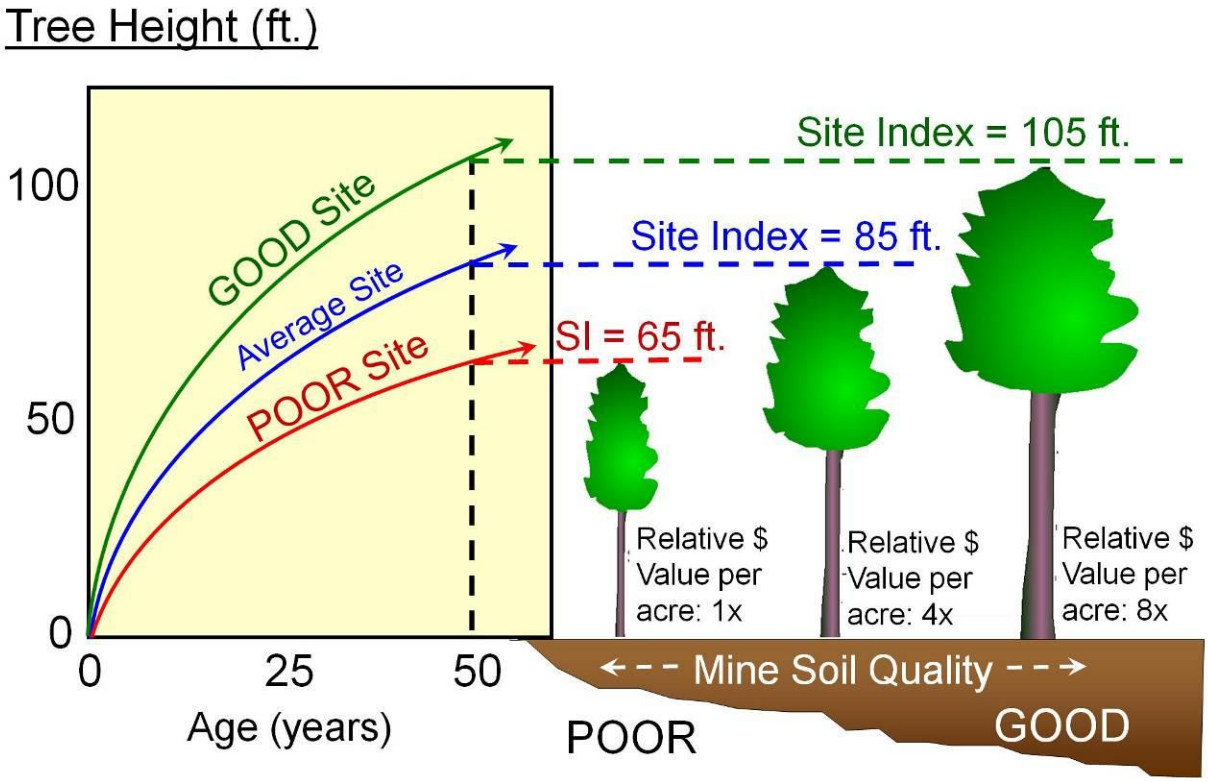

Figure 11. Predicted height (site index) of white pine trees 50 years after planting on three different mine soil types. As height increases, volume of trees and relative stem values increase exponentially (figure courtesy of Jim Burger, Virginia Tech).

Ecosystem Development

Another advantage of using weathered brown sandstone (and especially if some native topsoil is included) as a topsoil material is the much greater recruitment of native plants on the site. Recruitment of plants can occur because seeds and roots contained in the replaced native topsoil can germinate and sprout, but also because the weathered brown sandstone provides a soil medium conducive to native plant establishment from adjacent undisturbed areas (Holl et al., 2001). On disturbed lands with productive soil materials at the surface and without competition from seeded aggressive forage species, many native species will quickly colonize and proliferate on the site (Fig. 7 and 9). For example, at a mine site in Kentucky that was reclaimed using topsoil from the adjacent forest, 63 species from the natural forest were found on the reclaimed mine site within one year after the topsoil was spread (Hall, 2007). The use of weathered brown sandstone material, along with any excavated soil containing live seeds and roots from the native forest will greatly accelerate natural succession and the development of a diverse and productive forest ecosystem (Groninger et al., 2007).

Figure 12. Dr. Jim Burger shows the differences in stem diameter of white pine grown on three different spoil types. All stems are 18 years old. The smallest stem was grown on a siltstone, compacted soil, while the largest was grown on uncompacted sandstone spoils.

Topsoil Salvage

In some areas of the region, the native topsoil is thin and may be lost during site preparation for mining. Any of this material that can be saved and used to supplement the weathered brown sandstone placed at the surface is recommended. This topsoil contains forest floor seed, coarse woody debris, root wads, root fragments, and other root propagules, which can greatly enhance natural colonization of native forest plants onto the site. These plants will add diversity to the plant community and aid in forest ecosystem development. Native soil materials also contain plant available nitrogen and phosphorus, nutrients that are in low supply in most topsoil substitutes, including weathered sandstones that are not mixed with soil materials, but are also essential to tree growth. Topsoil materials along with organic matter debris can also enhance water infiltration and hydrologic properties.

Summary and Conclusions

Step 1 of the FRA states: Create a suitable rooting medium for good tree growth that is no less than 1.2 m deep and comprised of topsoil, weathered sandstone and/or the best available material. Creating a soil medium with physical and chemical properties that are favorable for growing trees is an essential foundation for mine reclamation practices to establish forested post-mining land uses. When native topsoil is not abundant, several types and mixes of overburden can be selected for placement on the surface of Appalachian surface mines as growth media. These spoil types include weathered brown sandstone, and mixtures of unweathered gray sandstone, siltstone, shale with topsoil and weathered materials. In studies of tree survival and growth in these spoil types, ***tree survival*** is often not significantly different among spoil types. Weathered brown, unweathered gray, and siltstone and shale materials all generally produce good tree survival (>70%) when compaction and competitive ground covers are reduced. Clearly, however, ***growth*** for most trees (as measured by height, diameter, and volume) was shown to be significantly greater in weathered brown materials than in unweathered gray, siltstone, shale, and mixed spoils. At one site in West Virginia five years after planting, a 10-fold difference in tree volume was found between these two spoil types. These tree volume differences with brown sandstone and high-pH gray sandstone have been found at other sites on Appalachian surface mines.

Therefore, based on the results of these studies, the use of topsoil alone, topsoil mixed with weathered brown sandstone or topsoil mixed with weathered brown sandstone and some unweathered rock materials are generally recommended to be placed on the surface of graded spoils on sites where hardwood tree species are being planted for forestry post-mining land uses. Salvaging a mixed, single strip of the combined O, A, E, B, and C horizons including the weathered rock immediately beneath the soil is practical and cost efficient. Favorable weathered brown sandstone spoil materials have a pH (4.5 to 6.5), soluble salt content (<0.4 ds m^{-1}), fine earth content (up to 50-60% fines), and sufficient nutrient supplying and water holding capacity that results in superior tree growth compared to other spoil types. The weathered sandstone material more closely resembles the native forest soil compared to unweathered spoil materials.

References

Andersen, C.P., B.H. Bussler, W.R. Chaney, P.E. Pope, and W.R. Byrnes. 1989. Concurrent establishment of ground cover and hardwood trees on reclaimed mined land and unmined reference sites. For. Ecol. Manage. 28:81–99. http://dx.doi.org/10.1016/0378-1127(89)90062-5.

Andrews, J.A., J.L. Torbert, J.E. Johnson, and J.A. Burger. 1992. Effects of minesoil properties on young white pine (*Pinus strobus*) height growth. p. 119-129. *In*: Proc., 1992 American Society of Mining and Reclamation Meet. Duluth, MN. 14-18 June 1992. R.I. Barnhisel (ed.) ASMR, Lexington, KY.
https://doi.org/10.21000/JASMR92010119

Angel, P.N., C.D. Barton, R.C. Warner, C. Agouridis, T. Taylor, and S.L. Hall. 2008. Tree growth and natural regeneration, and hydrologic characteristics of three loose-graded surface mine spoil types in Kentucky. Proceedings America Society of Mining and Reclamation, 2008 pp ~~1-40.~~ pp 28-65
https://doi.org/10.21000/JASMR08010028

Appalachian Regional Reforestation Initiative (ARRI). 2011. Trees for Appalachia's Future. http://arri.osmre.gov/ (verified 23 Jan 2011). US Office of Surface Mining.

Ashby, W.C. 2006. Reflections of a botanist on reclamation to trees. Reclamation Matters, Vol. 3, Issue 2, Fall 2006. Am. Soc. of Mining and Reclamation, Lexington, KY.

Ashby, W.C., W.G. Vogel, C.A. Kolar and G.R. Philo. 1984. Productivity of stony soils on strip mines. p. 31-44. *In*: J.D. Nichols et al. (ed.) Erosion and productivity of soils containing rock fragments. Special Publ. 13. Soil Sci. Am., Madison, WI.

Brown, J.H. 1962. Success of tree planting on strip-mined areas in West Virginia. West Virginia Agric. and Forestry Exp. Stn. Bull. 473. West Virginia Univ, Morgantown

Burger, J., D. Graves, P. Angel, V. Davis, and C. Zipper. 2005. The forestry reclamation approach. U.S. Office of Surface Min. Forest Reclam. Advisory No.2. 4 p. Available online at http://arri.osmre.gov (Verified 10 Oct. 2010.)

Burger, J.A, D. Mitchem, and W.L. Daniels. 2007. Red oak seedling response to different topsoil substitutes after five years. Proceedings America Society of Mining and Reclamation, 2007 pp 132-142. http://dx.doi.org/10.21000/JASMR07010132.

Casselman, C.N., T.R. Fox, J.A. Burger, A.T. Jones, and J.M. Galbraith. 2006. Effects of silvicultural treatments on survival and growth of trees planted on reclaimed mine lands in the Appalachians. For. Ecol. Manag. 223: 403-414. http://dx.doi.org/10.1016/j.foreco.2005.12.020.

Chaney, W.R., P.E. Pope, and W.R. Byrnes. 1995. Tree survival and growth on land reclaimed in accord with Public Law 95–87. J. Environ. Qual. 24:630–634. http://dx.doi.org/10.2134/jeq1995.00472425002400040013x.

Daniels, W.L., and D.F. Amos. 1984. Generating productive topsoil substitutes from hard rock overburden in southern Appalachians. Environ. Geochem. Health 7: 8-15. http://dx.doi.org/10.1007/BF01875045.

DeLong, C. 2010. Evaluation of reforestation efforts on two reclaimed surface mines in West Virginia. Thesis, West Virginia University, Morgantown, WV. 124 pp.

Emerson, P, J. Skousen, and P. Ziemkiewicz. 2009. Survival and growth of native hardwoods in brown vs gray sandstone on a reclaimed surface mine in West Virginia. J. Environ. Qual. 38: 1821-1829. http://dx.doi.org/10.2134/jeq2008.0479.

Gorman, J., J. Skousen, J. Sencindiver, and P. Ziemkiewicz. 2001. Forest productivity and minesoil development under a white pine plantation versus natural vegetation after 30 years. Proceedings America Society of Mining and Reclamation, 2001 pp. 103-111.

https://doi.org/10.21000/JASMR01010103

Groninger, J., J. Skousen, P. Angel, C. Barton, J. Burger, and C. Zipper. 2007. Mine reclamation practices to enhance forest development through natural succession. Forest Reclamation Advisory No. 5, July 2007, Appalachian Regional Reforestation Initiative. http://arri.osmre.gov/

Haering, K.C., W.L. Daniels, and J.A. Roberts. 1993. Changes in mine soil properties resulting from overburden weathering. J. Environ. Qual. 22: 194–200. http://dx.doi.org/10.2134/jeq1993.00472425002200010026x.

Hall, S. 2007. Topsoil seed bank of an Oak-Hickory forest in eastern Kentucky as a restoration tool on surface mines. M.S. Thesis, University of Kentucky, Lexington, KY. 92 pp.

Holl, K., C. Zipper, and J. Burger. 2001 Recovery of native plant communities after mining. Virginia Cooperative Extension Publication 460-140. http://pubs.ext.vt.edu/460/460-140/460-140.html

Isabell M. 2001. Special handling and unique mining practices at Fola Coal Company. *In*: Skousen J (ed). Proceedings, 22nd West Virginia Surface Mine Drainage Task Force Symposium, Morgantown WV.

Johnson, C., and J. Skousen. 1995. Minesoil properties of 15 abandoned mine land sites in West Virginia. J. Environ. Qual. 24: 635-643. http://dx.doi.org/10.2134/jeq1995.00472425002400040014x.

Plass, W.T. 1982. The impact of surface mining on the commercial forests of the United States. p. 1-7. *In*: C.A. Kolar and W.C. Ashby (Eds.), Post-mining Productivity with Trees. March 31-April 2, 1982, Southern Illinois University, Carbondale, IL.

Potter, H.S., S. Weitzman, and G.R. Trimble. 1955. Reforestation of stripped-mined lands. West Virginia Agriculture and Forestry Experiment Station Mimeograph Circular 55. West Virginia University, Morgantown.

Rodrigue, J.A., and J.A. Burger. 2004. Forest soil productivity of mined land in the Midwestern and eastern coalfield regions. Soil Sci. Soc. Am. J. 68: 833–844. http://dx.doi.org/10.2136/sssaj2004.8330.

Sencindiver, J.C., and J.T. Ammons. 2000. Minesoil genesis and classification. p. 595–613. *In:* R. Barnhisel et al. (ed.) Reclamation of drastically disturbed lands. 2nd ed. Agron. Monogr. 41, ASA, CSSA, and SSSA, Madison, WI.

Skousen, J., J. Gorman, E. Pena-Yewtukhiw, J. King, J. Stewart, P. Emerson, and C. DeLong. 2009. Hardwood tree survival in heavy ground cover on reclaimed land in West Virginia: mowing and ripping effects. J. Environ. Qual. 38: 1400-1409. http://dx.doi.org/10.2134/jeq2008.0297.

Skousen, J., C. Johnson, and K. Garbutt. 1994. Natural revegetation of 15 abandoned mine land sites in West Virginia. J. Environ. Qual. 23: 1224-1230. http://dx.doi.org/10.2134/jeq1994.00472425002300060015x.

Skousen, J.G., P. Ziemkiewicz, and C. Venable. 2006. Tree recruitment and growth on 20-year-old, unreclaimed surface mined lands in West Virginia. Int. J. Mining Reclam. Environ. 20:142–154. http://dx.doi.org/10.1080/17480930600589833.

Torbert, J.L., and J.A. Burger. 2000. Forest land reclamation. p. 371–398. *In* R.I. Barnhisel et al. (ed.) Reclamation of drastically disturbed lands. 2nd ed. Agron. Monogr. 41. ASA, CSSA, and SSSA, Madison, WI.

Torbert, J.L., J.A. Burger, and W.L. Daniels. 1990. Pine growth variation associated with overburden rock type on a reclaimed surface mine in Virginia. J. Environ. Qual. 19: 88-92. http://dx.doi.org/10.2134/jeq1990.00472425001900010011x.

Torbert, J.L., A.R. Tuladhar, J.A. Burger, and J.C. Bell. 1988. Minesoil property effects on the height of ten-year-old white pine. J. Environ. Qual. 17: 189-192. http://dx.doi.org/10.2134/jeq1988.00472425001700020004x.

Tryon, E.H. 1952. Forest cover for spoil banks. West Virginia Agriculture and Forest Experiment Station Bulletin 357. West Virginia University, Morgantown.

Zeleznik, J., and J. Skousen. 1996. Survival of three tree species on old reclaimed surface mines in Ohio. J. Environ. Qual. 25: 1429-1435. http://dx.doi.org/10.2134/jeq1996.00472425002500060037x.