

# ASMR Annual Meeting

June 2-6, 2013

Laramie WY

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## Rebuilding Soils for Forest Restoration in Appalachia

C. Zipper, Virginia Tech

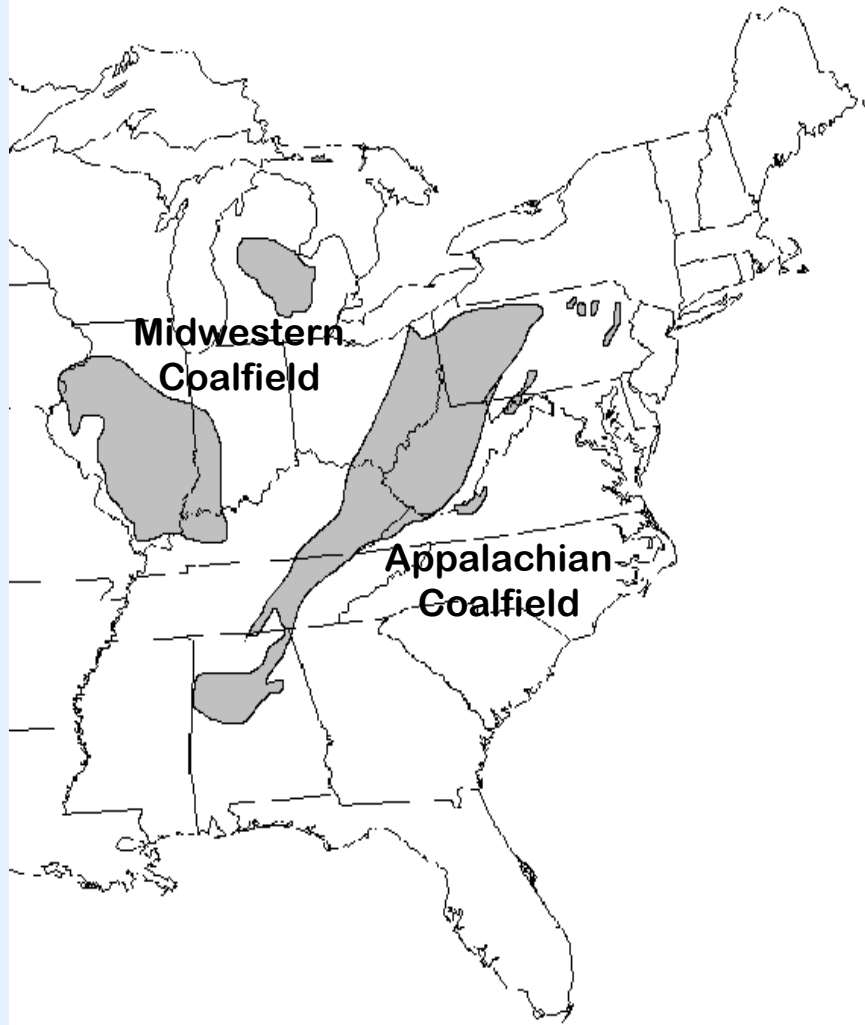
J. Burger, Virginia Tech

C. Barton, U. Kentucky

J. Skousen, West Virginia U.



# Eastern United States Coalfield Regions

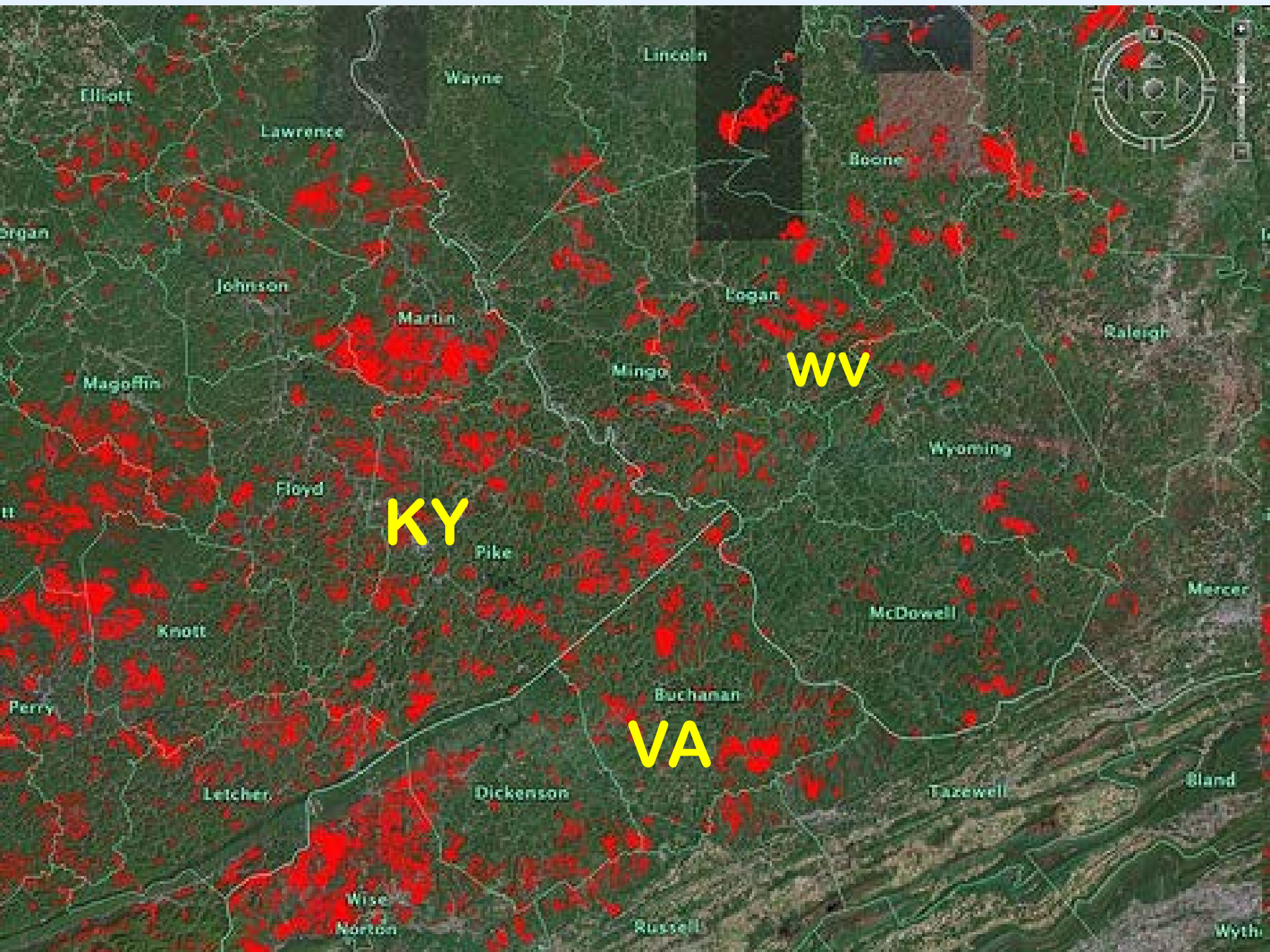


**Native Hardwood Forest**



**Surface Mining for Coal**

**700,000 hectares disturbed by mining  
in the Appalachian Region**







**Reasons to do better:**

- **SMCRA**
- **Environmental stewardship - restore ecosystem services - landscape aesthetics.**
- **Negative public perceptions - negative effects on industry.**



# Forest Reclamation Approach (FRA):

1. Create a *suitable rooting medium* for good tree growth no less than 4 ft deep, comprised of topsoil, weathered sandstone and/or best available material.
2. Loosely grade the topsoil or topsoil substitute established in step one to create a *noncompacted growth medium*.
3. Use *ground covers* that are compatible with growing trees.
4. Plant *2 types of trees* - early successional for wildlife and soil stability, and commercially valuable crop trees.
5. Use *proper tree planting techniques*.



# Presentation Purpose:

Describe “best available material” for soil construction when reforesting mines in Appalachia, Interpreting available science.




## Outline:

1. Review studies that identify mine soil properties favorable to growth of native trees.
2. Review studies that compare material selection effects directly.
3. Review tree productivity studies.
4. Describe “best available” materials for reforestation, based on reviewed studies.

# This presentation is based on published work:

J. Skousen, C. Zipper, J. Burger, C. Barton, P. Angel. 2011. Selecting materials for mine soil construction when establishing forests on Appalachian mine sites. ARRI FR Advisory No. 8.

C. Zipper, J. Burger, C. Barton, J. Skousen. 2013. Rebuilding soils on mined land for native forest in Appalachia, USA. *Soil Sci. Soc. Am J.* 77: 337-349.



THE APPALACHIAN REGIONAL REFORESTATION INITIATIVE (ARRI)  
**FOREST RECLAMATION ADVISORY**  
Forest Reclamation Advisory No. 8 July 2011

### SELECTING MATERIALS FOR MINE SOIL CONSTRUCTION WHEN ESTABLISHING FORESTS ON APPALACHIAN MINE SITES

Jeff Skousen, Carl Zipper, Jim Burger, Christopher Barton, and Patrick Angel

The Forest Reclamation Approach (FRA) is a method for reclaiming coal-mined land to forest (FRA Advisory #2, Burger and others 2005). The FRA is based on research, knowledge, and experience of forest soil scientists and reclamation practitioners. Forest Reclamation Advisories are guidance documents that describe state-of-the-science procedures for mined land reforestation [see [http://arri.osmre.gov/FRA/FRA\\_shttm](http://arri.osmre.gov/FRA/FRA_shttm)].

The FRA's first step is: "create a suitable rooting medium for good tree growth that is no less than 4 feet deep and comprised of topsoil, weathered sandstone and/or the best available material." This Advisory provides guidance on how to execute step 1 of the FRA.

Selection and placement of suitable growth media are critical for successful reforestation on surface mines. Constructing mine soils using suitable materials enhances and accelerates development of diverse forest ecosystems. This Advisory is intended for mining operators seeking to re-establish native forest as a post-mining land use with pre-mining capability on coal surface mines.

#### Background

Soil is a mixture of weathered rocks, organic material, water, air, and living creatures. Its properties provide the structural support and other resources necessary for plant and animal life in a forest. The soil is the foundation of a forest ecosystem. Indeed, the health

and productivity of a forest are determined by the nature and properties of the soil.

The eastern USA's Appalachian Mountains are among the world's most ancient landscapes. The region's soils have developed from the rocks that form these landscapes over long time periods in response to climate, plants and animals, and landscape position (Jenny, 1941). Throughout the Appalachians, diverse plant communities have evolved over millennia on these weathered rock and soil materials (Figure 1).

Weathering is the process of changing rocks into soil-like materials. During surface mining, unweathered rocks are often placed on the surface as growth media. These rocks react with air and water and break down physically and chemically, releasing soluble salts and changing mineral forms (Sencindiver and Ammons, 2000). Plants can establish and grow in these pre-soil materials, producing organic matter to aid soil development and making the growth media more favorable for colonization by microorganisms and other plants (Johnson and Skousen, 1995). These processes are well known, occur naturally, and can be accelerated by reclamation activities such as fertilizing and seeding. However, when starting with unweathered rocks, very long time periods are required to produce a soil that can support a plant community like the one which existed before mining (Figure 2).

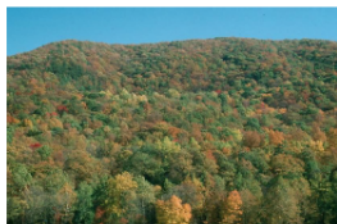


Figure 1. The Mixed Mesophytic Forest of the Appalachian mountains is a diverse assemblage of over 40 tree species that depend on native soil properties and other environmental factors

1

Review and Analysis—Forest, Range & Wildland Soils

## Rebuilding Soils on Mined Land for Native Forests in Appalachia

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The eastern U.S. Appalachian region supports the world's most extensive temperate forests, but surface mining for coal has caused forest loss. New reclamation methods are being employed with the intent of restoring native forest on Appalachian mined lands. Mine soil construction is essential to the reforestation process. Here, we review scientific literature concerning selection of mining materials for mine soil construction where forest ecosystem restoration is the reclamation goal. Successful establishment and productive growth of native Appalachian trees has been documented on mine soils with coarse fragment contents as great as 60% but with low soluble salt levels and slightly to moderately acidic pHs, properties characteristic of the region's native soils. Native tree productivity on some Appalachian mined lands where weathered rock spoils were used to reconstruct soils was found comparable to productivity on native forest sites. Weathered rock spoils, however, are lower in bioavailable N and P than native Appalachian soils and they lack live seed banks which native soils contain. The body of scientific research suggests use of salvaged native soils for mine soil construction when forest ecosystem restoration is the reclamation goal, and that weathered rock spoils are generally superior to unweathered rock spoils when constructing mine soils for this purpose.

Abbreviations: CI, coarse fragments (>2 mm); EC, electrical conductivity; SI, site index; SMCRA, Surface Mining Control and Reclamation Act.

Eastern U.S. Appalachian region supports the world's most extensive temperate deciduous forests (Ritters et al., 2000), but these forests are being lost due to expanding surface coal mining. Appalachian forests are significant ecological and commercial resources, with nearly 40 commercially important trees and associated plant species forming what are among the world's most diverse non-tropical ecosystems (Ricketts et al., 1999). Appalachian forests also store large quantities of C in soil and biomass, and they provide ecosystem services, including watershed and water quality protection, and plant and faunal habitat. The region's forests provide commercial timber, support a forest industry that is a major regional employer, and supply forest products for economic uses worldwide. Coal surface mining is also an important industry and employer within the region.

More than 600,000 ha of land have been mined for coal in Appalachia since the late 1970s (Zipper et al., 2011b). Over that time, the Appalachian region has experienced significant forest loss and fragmentation (Wickham et al., 2007; Sayler, 2008; Townsend et al., 2009; Drummond and Loveland, 2010). Zipper et al. (2011a) assessed 25 mine sites randomly selected from mining agency databases in four states, mined and reclaimed under the Surface Mining Control and Reclamation Act (SMCRA), and found these lands not in active

*Soil Sci. Soc. Am. J.* 77:337–349  
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Received 2 Oct. 2012  
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Soil Science Society of America Journal



Soil compaction is well known as a factor that inhibits tree growth – avoiding soil compaction is essential for mine reforestation.



That is FRA Step 2 – Not the focus here.



# 1. Mine soil properties favorable to growth of native trees.

## DIVISION S-4—SOIL FERTILITY & PLANT NUTRITION

### Forest Soil Productivity of Mined Land in the Midwestern and Eastern Coalfield Regions

J. A. Rodrigue and J. A. Burger\*

#### ABSTRACT

The goal was to determine the effects of surface mining on forest land productivity in the eastern coalfields of the USA before the passage of the Surface Mining Control and Reclamation Act of 1977 (SMCRA), and to determine the extent to which selected mine soil properties influenced forest productivity. The site productivity of 14 mined and eight nonmined sites in the eastern and midwestern coalfields were compared. Results show that the productivity of assumed

safety, land productivity, and environmental problems that occurred during mining and reclamation. However, in the process of attaining these goals, reforestation discontinuities were created because the reclaimed landscape is difficult to plant to trees and it is common unproductive for forestry (Burger, 1999). Postmine plants was placed on water quality and erosion control (Boyer, 1999) at the expense of site productivity, reclamation, C sequestration, and productive land trees many cases, reclamation in the Appalachian region suits in mine soils that are alkaline, highly compact and covered with competitive grasses, which make difficult to re-establish forests and causes them to be poorly (Burger, 1999). Nonetheless, the Code of Federal Regulations (1997 Section 751.151) has inter-

to be used as a benchmark to assess the impacts of on mine soil quality and forest productivity.

MINING has been disturbing land, forests ways of the midwestern and eastern U.S. Since the implementation of the SMCRA Office of Surface Mining statistics 40 ha have been disturbed by mining (1999). We estimate that an equivalent had before 1978, although the exact amount before federal regulations controlling the nature of mining disturbance prompted (miners, landowners, and surrounding commu-

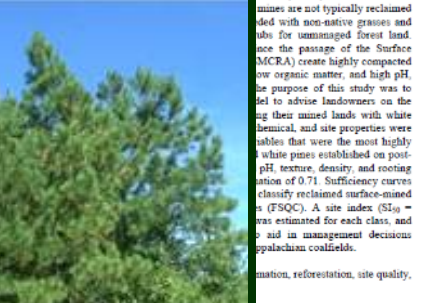
largely under rugged mountain forests, soils, and bedrock are mines are not typically reclaimed due with non-native grasses and tubs for unmanaged forest land. Since the passage of the Surface MCR) create highly compacted or organic matter, and high pH, the purpose of this study was to help to advise landowners on the mg their mined lands with white chemical, and site properties were able to be the most highly white pines established on post-pH, texture, density, and rooting station of 0.71. Sufficiency curves classify reclaimed surface-mined a (FSQC). A site index (Site = was estimated for each class, and aid in management decisions Appalachian coalfields.

reclamation, reforestation, site quality,

### DEVELOPMENT OF A FOREST SITE QUALITY CLASSIFICATION MODEL FOR MINE SOILS IN THE APPALACHIAN COALFIELD REGION<sup>1</sup>

Andy T. Jones<sup>2</sup>, John M. Galbraith, and James A. Burger

Abstract: The Appalachian coalfields occur



#### Land Reclamation

### Minesoil and Site Properties Associated with Early Height Growth of Eastern White Pine

Jeffrey A. Andrews, James E. Johnson, John L. Torbert, James A. Burger, and Daniel E. L.

#### ABSTRACT

A study was established to investigate soil and site variables associated with early growth of eastern white pine (*Pinus strobus* L.) on reclaimed land sites in southern West Virginia and Virginia. A total of 76 plantations were established in 14 different mines. Five by following planting. The soil was analyzed for pH, organic matter, and available nutrients. The growth rate in a white pine saplings a quarter decade to three the relationship between tree growth and soil and site variables. More soil variables were used, but soil depth, depth, chemical conductivity, surface soil pH, and soil depth were the most important variables. Soil depth was the most important variable in growth, but depth had a weak relationship between soil depth, and was the most significant variable. Through proper reclamation, it is possible to establish a site that will not only provide for adequate early height growth to facilitate land use, but also provide for better long-term productivity of re-mined lands.

THE EASTERN COAL REGION of the USA is predominantly forested. Following strip mining, the reclaimed land is often returned to forest under the provisions of the Surface Mining Control and Reclamation Act (SMCRA, Public Law 95-87) in Virginia when untransported forest is selected as the post-mining land use and complete reforestation. Some that exceeds 1000 meters  $\times$  20 cm in height after 5 yr. In West Virginia, the requirement is 60 stems of dominant species. Reclamation to forest presents an opportunity to create a new ecosystem with a variety of commercially valuable species; however, reclamation practices must be tailored to suit the survival and growth of trees.

Eastern white pine, which occurs naturally throughout the Eastern Coal Region, occurs at the most common commercial tree species used in reclamation. Its productivity, tolerance of site conditions, and growth characteristics

The study was funded by Bill Coors, Mercer, West Virginia, and M. Denise Costello.

### Minesoil Property Effects on the Height of Ten-Year-Old White Pine

J. L. TORBERT,\* A. R. TULADAR, J. A. BURGER, AND J. C. BELL

#### ABSTRACT

Thirty-five 10-year-old white pine (*Pinus strobus* L.) growing on reclaimed minefields in Virginia were selected to evaluate the effects of mineral nutrient properties on tree growth. A 1-m deep bucket soil core was taken from each tree to determine rooting depth, and surface soil samples (0–10 cm) were subjected to analysis of nutrient chemical and chemical properties. Multiple regression analysis was used to model the combined effects of mineral properties on tree height. The mineral variable that had the greatest influence on tree growth was rooting volume index, defined as depth to restrictive layer times the soil-water fraction (%) of the surface 10 cm. The most useful mineral nutrient property that affected height was available soil content, as measured by soil-water content. A linear regression equation describing white pine site index (Site) as a function of the square root of depth to a restrictive layer was highly significant.

Additional Index Words: Reclamation, Reforestation, Rooting Volume, Site Index, Soluble Salt, Plant Species I.

Most surface-mined land in the Appalachian Mountains was forested before mining and will ultimately return to forest after reclamation. Consequently, reclamation of surface-mined land frequently involves tree planting. Historically, white pine (*Pinus strobus* L.) has been an important tree species for reclamation in Virginia. White pine is more compatible than other pine species with herbaceous ground covers planned for erosion control because it can tolerate limited amounts of shade. On high-quality sites within its range, white pine is unrivaled in its ability to produce merchantable timber; large saplings can be harvested in 35- to 40-yr rotations (Ballner and Willison, 1983). Unfortunately, white pine is a site-sensitive species, and it is often planted on reclaimed areas that are unable to support good growth. Consequently, a wide range in white pine growth is exhibited on reclaimed mine sites in southwestern Virginia. The purpose of this study was to identify important growth-limiting factors on reclaimed mine sites by examining the relationship between some selected minesoil properties and the growth performance of white pine. The relationship between

Soil Act of 1977), and consisted of placing enough soil and/or loose overburden on the bench to support a cover of *Sorrelis lepidota* (*Lepidocytis* Oakes) (Dob), Black locust (*Robinia pseudoacacia* L.) was planted or hydroseeded on the outcrop, and three rows of white pine were densely planted along the edge of each bench. White pines were obtained from the Virginia Department of Forestry in 1.0 seedlings and had been growing on the site for 8 yr at the time of this study. Consequently, the trees were 10 yr old.

Thirty-four trees on a variety of sites were selected to represent a range of tree sizes and readily apparent minesoil characteristics, such as color and overburden type. Each tree stood on a given site represented the average size of adjacent trees and was thus considered to fairly represent typical tree growth for the immediate area. Total height, establishment growth rate, and terminal-dry increment were measured. Establishment growth rate (cm/yr) was defined as the average annual growth rate that occurred prior to the year the height growth exceeded the average of the two previous years by more than 100%. For most trees, the establishment period consisted of the first 3 or 4 yr. Terminal dry increment was the height increment (cm) that occurred during the last 4 yr.

Three surface soil samples (0–10 cm) were collected at each tree from systematically determined locations at half the core radius from the base of each tree. At each of these locations, bulk density was determined based on the oven-dry weight of the material removed from a cylindrical hole 10 cm deep and 10 cm in diam. The volume of bulk was determined by the amount of clean, dry sand used to back-fill the hole. Soils were air-dried, sieved through a 2-mm screen, and analyzed for organic matter, fragments, and analyzed for particle-size distribution by the hydrometer method. Soil pH was determined in a 1:1 soil-water mixture with a glass electrode (McLean, 1982), and soluble salts were determined by measuring the electrical conductivity (EC) of a 1:5 soil-water extract (Rhoades, 1982). Organic matter content, total Kjeldahl N, and available phosphorus (P) were determined by methods of Nelson and Sommers (1982), Blaney and Mulvaney (1982), and Kempe (1982), respectively. Phosphorus was extracted with NaOH<sub>3</sub> (Olsen and Somers, 1982) and determined by spectrophotometry. Exchangeable K, Ca, and Mg were extracted with 1 M NH<sub>4</sub>NO<sub>3</sub> and determined by flame emission (K) and atomic absorption spectrophotometry (Ca and Mg). A bucket of soil was dug at the base of each tree to determine rooting depth. Firs were dug to a depth of 1 m where possible. Rooting depth was measured as the depth to solid rock, or the depth to traffic pans with a minimum bulk density of 1.7 Mg

## “Regression Studies”

- o Identify growing trees on different mine sites.
- o Identify tree-growth metric that is comparable among sites.
- o Measure tree-growth metric and soil properties.
- o Identify soil properties that exhibit statistical associations with tree-growth metrics.

Soil properties  
controlling height (proxy  
for growth rate) of 10-yr old  
Eastern white pines  
(n=34), Virginia.



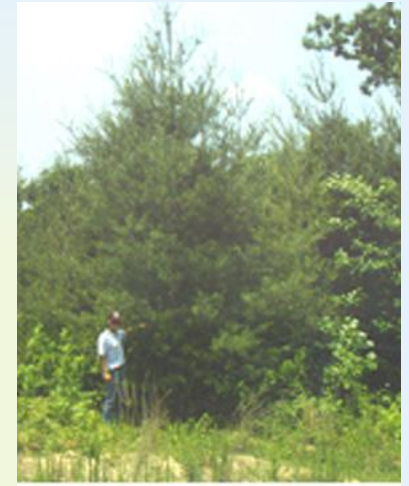
Tree rings from same age EWP

- ↑ Rooting volume (+ soil depth, - coarse fragments)
- ↓ Electrical conductivity (soluble salts)
- ↑ Soil Phosphorous

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 . *Journal of Environmental Quality* 17(2):189-192.



Soil factors  
controlling Eastern  
white pines 2-year  
terminal height  
growth; 78 trees,  
ages 4 - 5, on 14  
mines in VA & WV



Photos: both are 8 yr old eastern  
white pine (EWP)

↑ Rooting depth

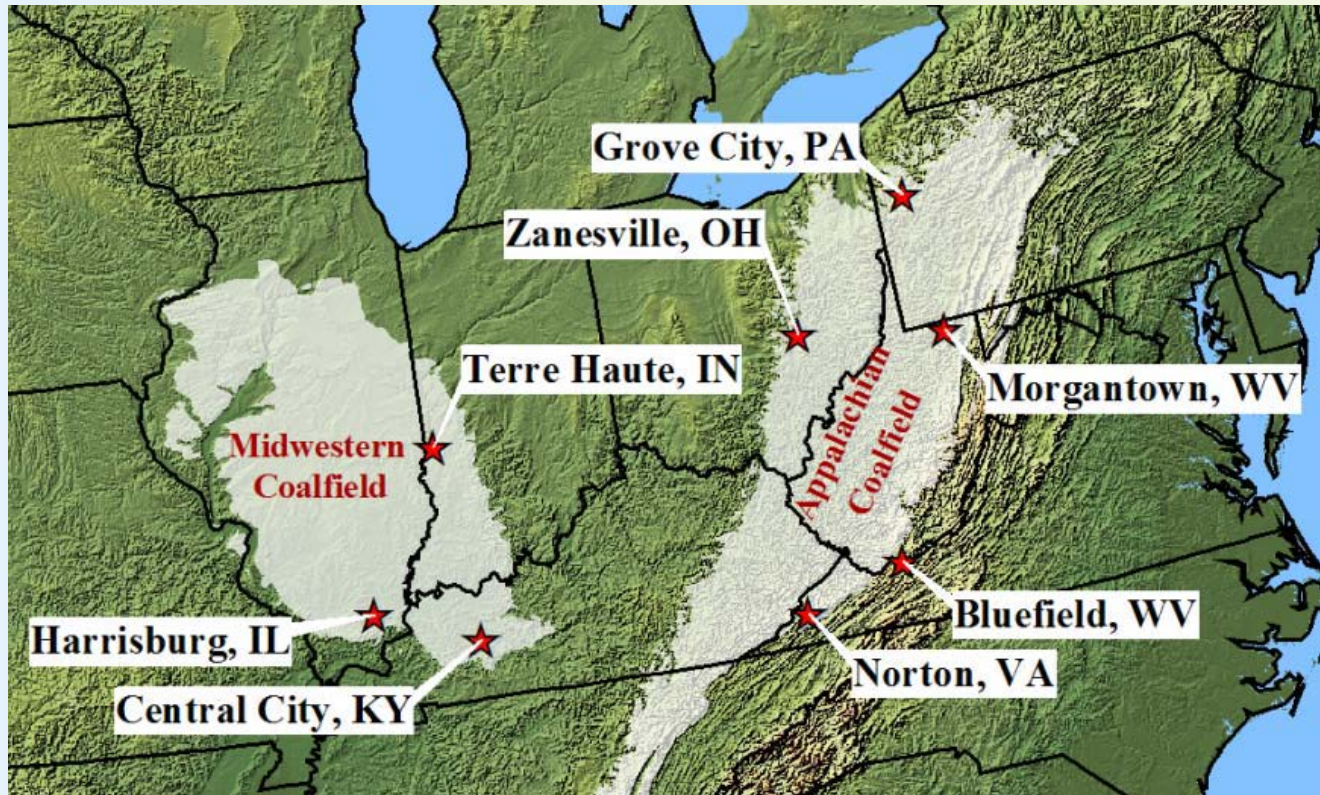
↓ Elec conductivity

↑ Soil Phosphorous

↑ Slope (compaction proxy?)

Andrews, J.A., J.E. Johnson, J.L. Torbert, J.A. Burger, and D.L. Kelting.  
1998. Minesoil properties associated with early height growth of eastern  
white pine. *Journal of Environmental Quality* 27:192-198.

**Jason Rodrigue** studied forest growth on pre-SMCRA mines: 14 study plots, 7 locations, 6 states.



J. Rodrigue  
and J. Burger.  
2004. Forest  
soil  
productivity of  
mined land in  
the  
midwestern  
and eastern  
coalfield  
regions.  
SSSAJ 68:  
833-844.

Measured site productivity for the species present was converted to 50-year white oak SI using published equations.



## Rodrigue's Findings:

Soil properties controlling 50-year White Oak site index for reforested pre-SMCRA mine sites.

- ↑ Base saturation  
(soil nutrients)
- ↓ Coarse fragments
- ↑ Total available water
- ↑ C-horizon porosity
- ↓ Elec. conductivity



Soil factors controlling the first 5 internodes from breast height of 10-18 year old Eastern white pines on 49 sites (4 trees/site) in VA & WV.



↓ Bulk Density

↑ Rooting depth

Loamy Texture

Moderately Acid pH

*Texture and pH Effects are non-linear*

Jones, A. T., J. M. Galbraith, and J. A. Burger. 2005. Development of a forest site quality classification model for mine soils in the Appalachian Coalfield Region. In: *Proceedings, 22nd Meeting, ASMR*



# What mine soil properties are favorable to tree growth - and are controlled by material selection?

Soil pH: Moderately acidic is best.

EC / soluble salts: should be low.

Soil P: must be adequate (but measurement technique makes a difference!)

Coarse Fragments: No evidence of negative effects up to ~ 60-70% - if soil depth is adequate.

Textural composition of soil fines: Loamy / sandy textures are best (may be less important on slopes than flats?).



# Materials selected for use in mine soil construction will influence mine soil properties



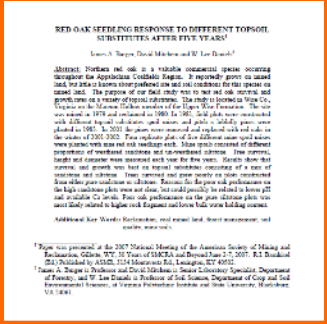
Generally, properties of weathered rock and soil are more "favorable" (as per these studies) than unweathered overburden material.



# 2. Direct Spoil Comparisons



VT: Burger & others  
“Controlled Overburden Placement” (1990 & 2007)



WVU:  
Emerson,  
Skousen



Angel,  
Barton



Miller,  
Barton



VT: Showalter,  
Burger (pot  
study)

Researchers established experimental plots using different types of spoil material, compared tree survival and/or growth among the materials.



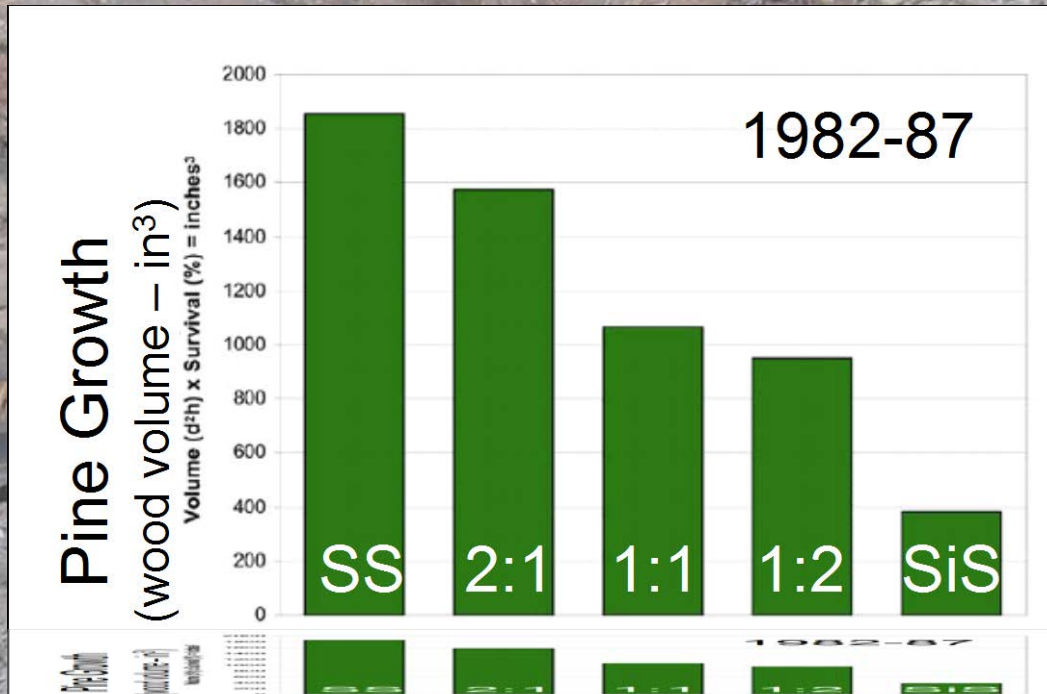
Controlled  
Overburden  
Placement  
“Rock Mix”  
Experiment.

Powell River Project,  
Va Tech.





(VT) Controlled  
Overburden  
Placement:  
Mix weathered  
sandstone (SS) +  
unweathered  
siltstone (SiS) in  
various ratios.



J. Torbert et al. 1990. Pine growth variation associated with overburden rock type on a reclaimed surface mine in Virginia. Journal of Environmental Quality 19:88-92.

# WVU: Weathered versus Unweathered Sandstone Catenary Coal Co. Samples Mine in Kanawha Co. WV.



Unweathered gray sandstone

Photos show tree growth after 6 years  
(10 App. hardwoods + e. white pine)



Weathered brown sandstone

*3-year data reported in:* P. Emerson, J. Skousen, and P. Ziemkiewicz. 2009. Survival and growth of hardwoods in brown versus gray sandstone on a surface mine in West Virginia. J. Environ. Qual. 38:1821–1829.



# UKy Experimental Plots at Bent Mountain KY.

MIXED

BROWN  
(weathered)

GRAY  
(unweathered)

Trees Planted:

Red Oak

White Oak

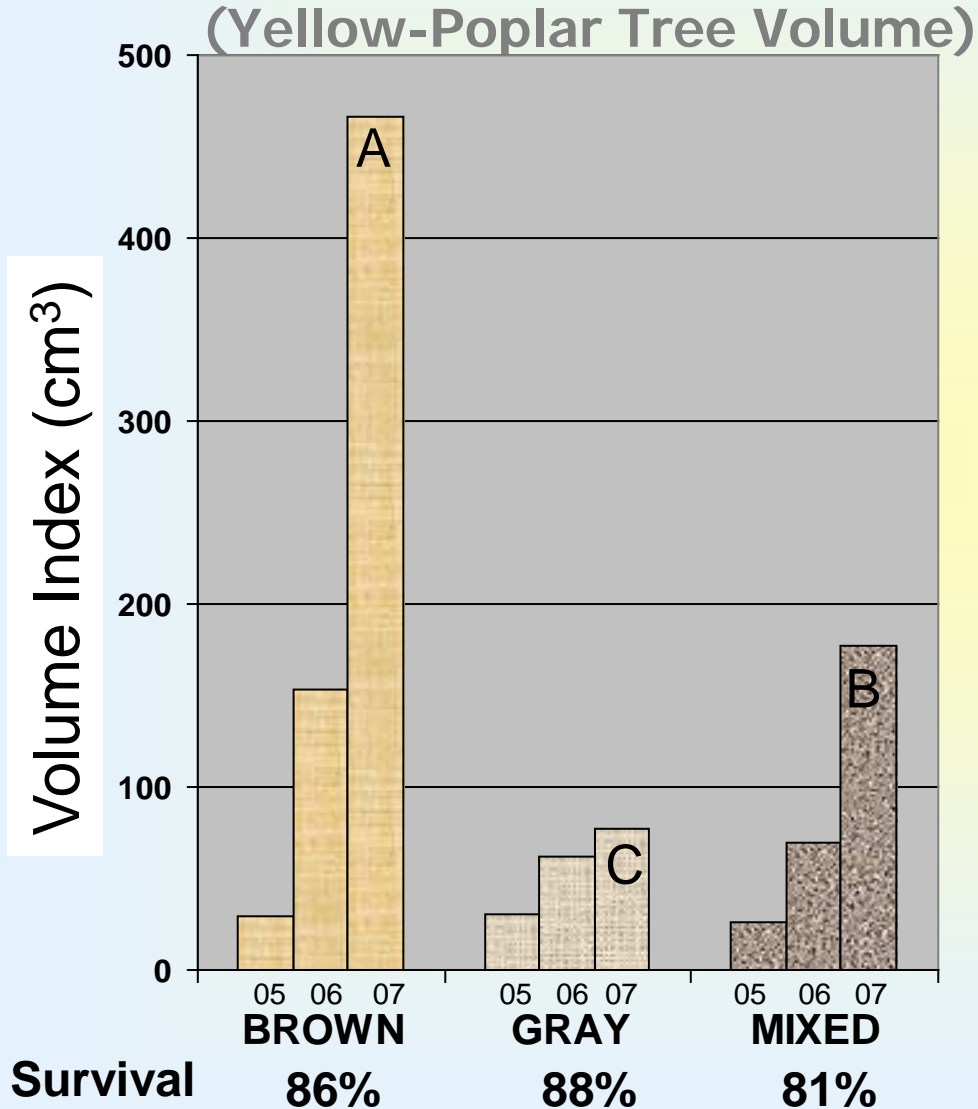
Yellow Poplar

Green Ash

P. Angel, C. Barton, et al.  
2008. Tree growth, natural  
regeneration, and hydrologic  
characteristics of three  
loosegraded surface mine  
spoil types in Kentucky. p. 28–  
65 in: ASMR Proc.



# Bent Mountain Project – 3YR Tree Response



(Brown Sandstone, 2007)



# Bent Mountain Project – 2YR Seedbank Response

(Natural Regeneration)



BROWN

66.4%  
cover

61 species



MIXED

5.8%  
cover

35 species



GRAY

2.0%  
cover

12 species

# UKy Experimental Plots, Bent Mountain, Study #2

**B**BROWN (Weathered)  
Sandstone

**G**RAY Sandstone

**S**hale

**M**ixed Sandstone  
& Shale

Trees:

9 spp.

Appalachian  
hardwoods



J. Miller, C. Barton, et al. 2012. Evaluating soil genesis and reforestation success on a surface coal mine in Appalachia. *Soil Sci. Soc. Am. J.* 76:950–960.





Miller et al. (2012) results over 2 years:

Mean tree survival ranged from 75% (unweathered shale) to 94% (weathered sandstone).

Mean tree growth was greater on weathered sandstone (94 cm) than on all other treatments (ranged from 47 – 60 cm)



# Mine soil comparison in greenhouse

Forest topsoil  
and spoils  
from  
Pritchard  
Mine, WV

White ash,  
red oak, tulip  
poplar  
(2-yr stock)

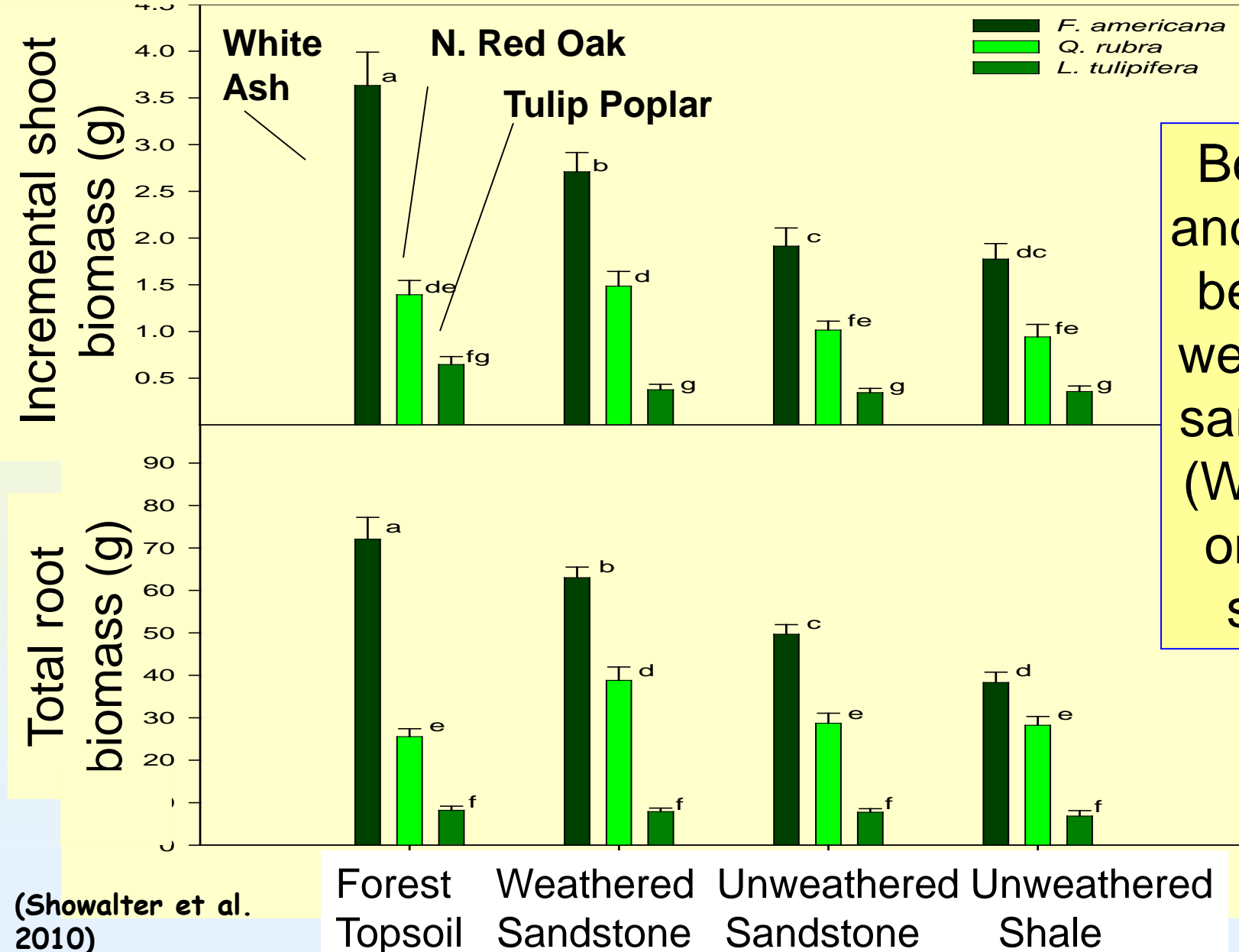
Study ran  
May-October.



J. Showalter, J.. Burger, C. Zipper. 2010. Hardwood seedling growth on different mine spoil types, with and without topsoil amendment. J. Environ. Qual. 39:483–491

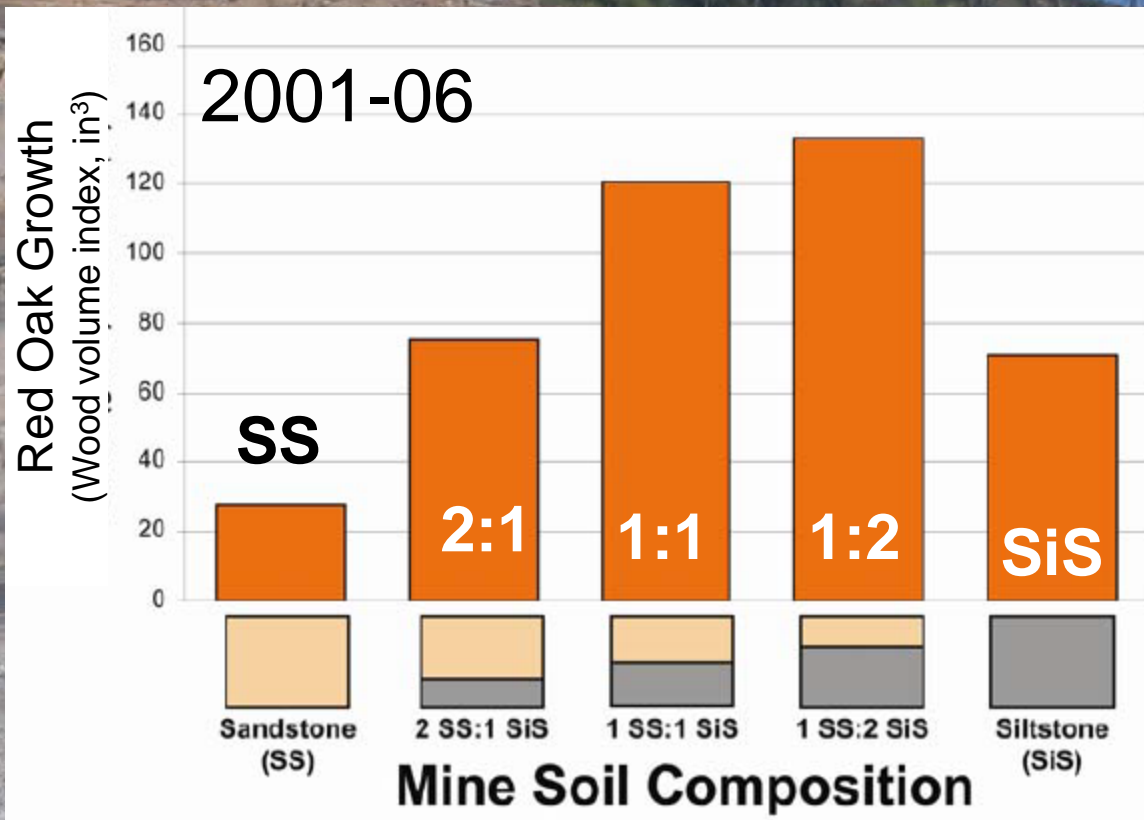


# Tree growth on different spoil types



Both oak and ash do better on weathered sandstone (WS) than on other spoils.

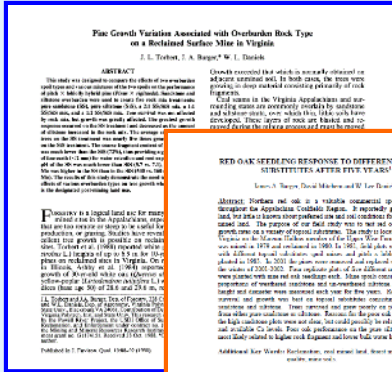
(VT) Controlled Overburden Placement: Mix weathered sandstone (SS) + unweathered siltstone (SiS) in various ratios.



J. Burger, D. Mitchem, W.L. Daniels. 2007. Red oak seedling response to different topsoil substitutes after five years. p. 132–142 in: ASMR Proceedings..



# Unweathered materials show different responses to environmental exposure.



VT: Burger "Controlled Overburden Placement"

WVU:  
Emerson,  
Skousen

Angel,  
Barton

UKy:

Miller,  
Barton

VT: Showalter,  
Burger (pot  
study)

Material:	SiS	SS	SS	SS	Sh*
Time:	2.5 yr	3 yr	3 yr	- 2 yr avg -	
pH:	6.4	8.1	8.5	8.8	6.8

\* Miller et al. unweathered shale had high EC, appears to be slightly pyritic

# 3. Forest Productivity Studies



E.W. Pine, VA,  
SMCRA- interim



Rodrigue, pre-  
SMCRA mines,  
6 states



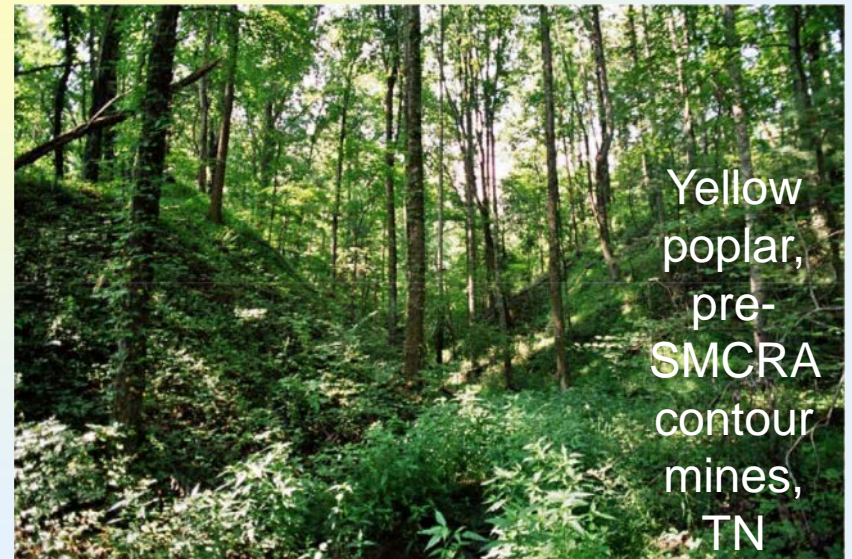
Cotton thesis, KY,  
W. Oak, Y. Poplar  
(over 9 years)



Post-SMCRA species  
trial, VA, PRP (15 yrs)



Martiki Mine, KY (compacted &  
ripped): 5 species, 18 yrs.



Yellow  
poplar,  
pre-  
SMCRA  
contour  
mines,  
TN





Eastern white pines established by active mining  
operation in 1979.

Measured 50-yr site index = 32 m, vs ~24 m Appalachian Avg.

C. Casselman et al. 2007. Northern Journal of Applied Forestry 24:9-13.



# Bottom Line on Tree Productivity Studies

Pre-mining productivity approached or obtained only when

- (1) weathered spoil is used for soil construction [in some cases mixed with soil and/or unweathered spoil]
- (2) spoil is loose graded (minimal or no compaction).



- 
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# Rebuilding Soils for Forest Restoration in Appalachia

- Key mine soil properties influencing forest site quality: depth & density (soil construction) - and pH, salts, coarse P content, fragments/texture, non-pyritic (material selection)
- Reapplying a mix of all soil horizons and weathered bedrock, uncompacted, can produce mine soils that restore forest site quality.
- When weathered materials are not available: unweathered materials vary widely in suitability for restoring forest cover. Selecting materials for favorable properties will influence reforestation success.
- Research issues remain (e.g. long-term capacity of weathered spoils to support tree nutrition, soil structure formation to support aeration and porosity, interpretations of raw-spoil measures vs. short-term weathering, etc.)



High diversity, native species (6 years after reclamation)



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