ASMR Annual Meeting

June 2-6, 2013 Laramie WY

Rebuilding Soils for Forest Restoration in Appalachia

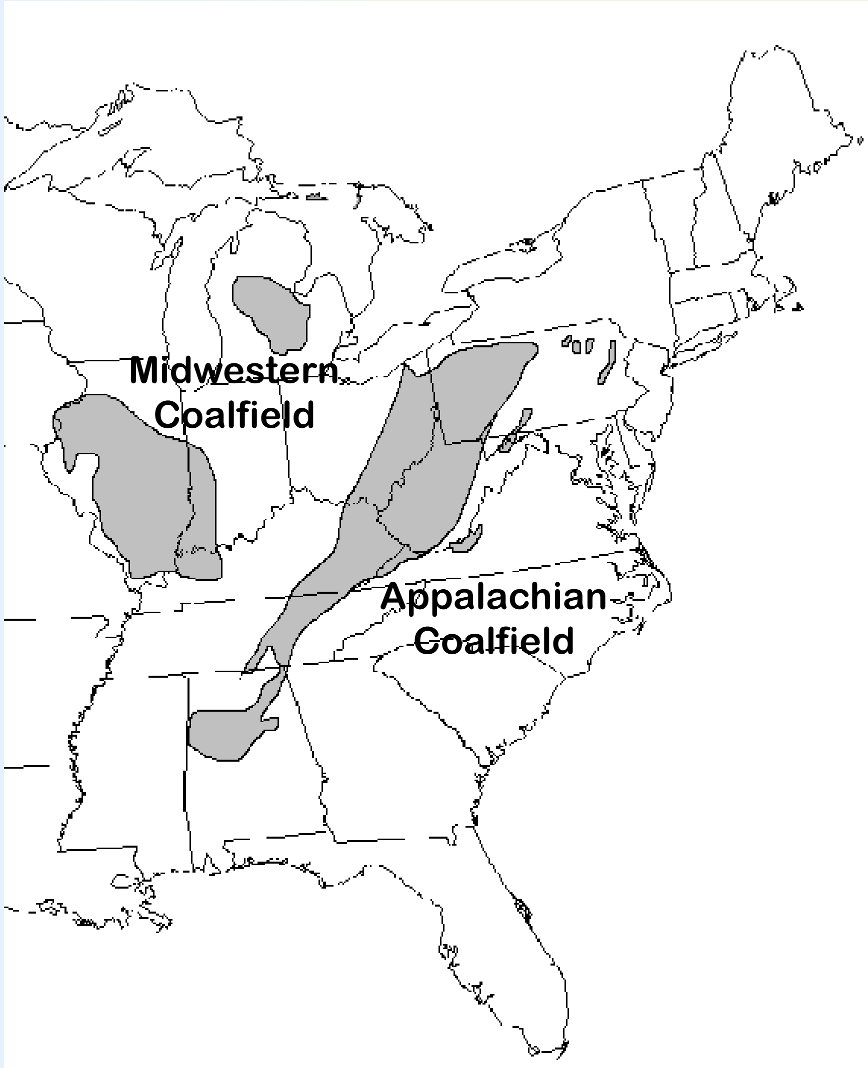
C. Zipper, Virginia Tech

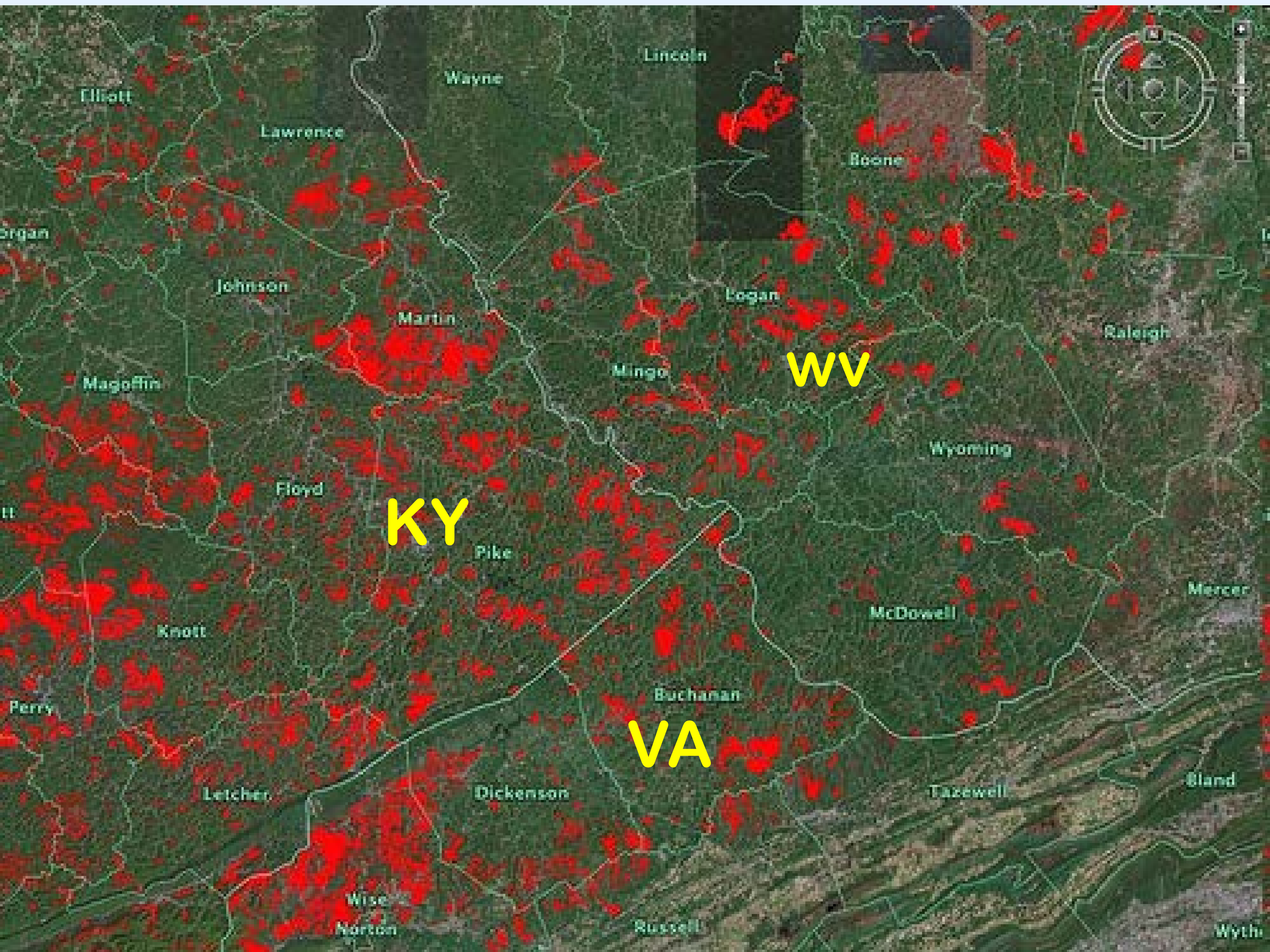
J. Burger, Virginia Tech

C. Barton, U. Kentucky

J. Skousen, West Virginia U.

Eastern United States Coalfield Regions




Lincoln
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Pike
Mercer
McDowell
Knott
Perry
Buchanan
VA
Letcher
Dickenson
Tazewell
Bland
Wise
Norton
Russell

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.

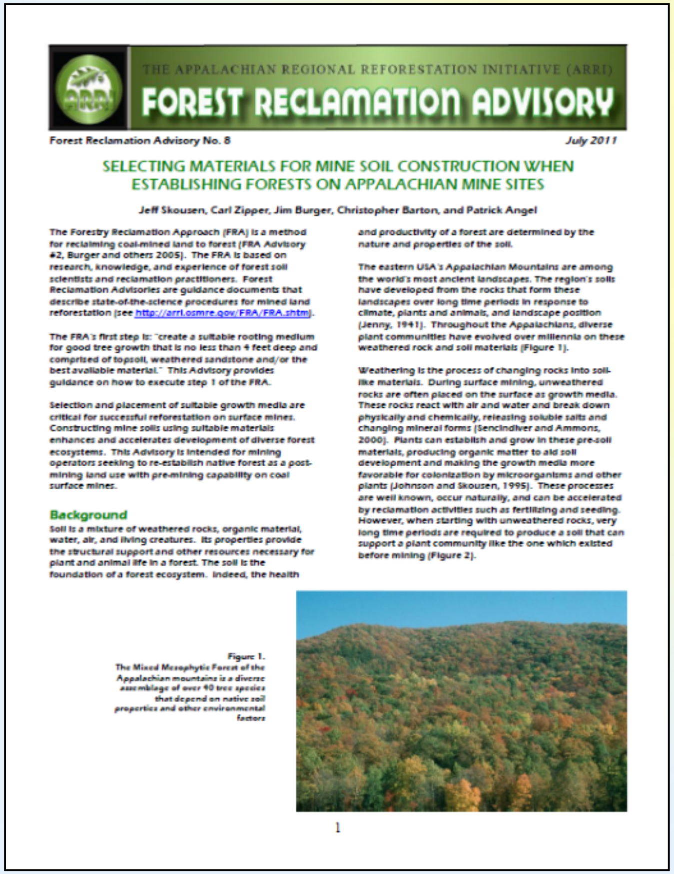
Outline:

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 forests 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 Forestry 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.shtm).

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: CF, 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 (Riitters et al., 2000), but those 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

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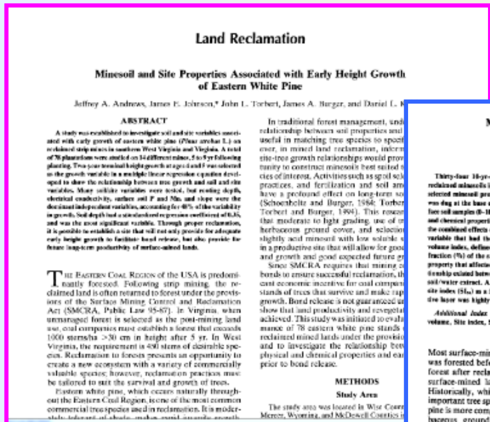
*Corresponding author (czip@vt.edu).

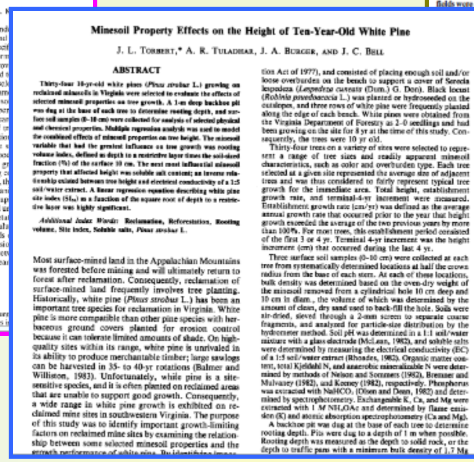
Soil compaction is well known as a factor that inhibits tree growth – avoiding soil compaction is essential for mine reforestation.

That is FRA Step 2 – Not the focus here.

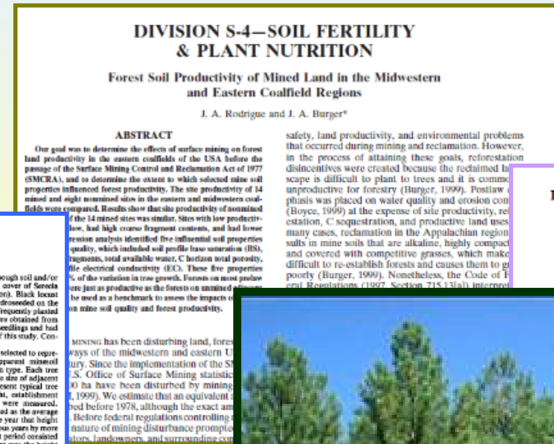
1.Mine soil properties favorable to growth of native trees.


Land Reclamation

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


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

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


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*


DEVELOPMENT OF A FOREST SITE QUALITY CLASSIFICATION MODEL FOR MINE SOILS IN THE APPALACHIAN COALFIELD REGION[1]

Andy T. Jones[2], John M. Galbraith, and James A. Burger

"Regression Studies"

- Identify growing trees on different mine sites.
- Identify tree-growth metric that is comparable among sites.
- Measure tree-growth metric and soil properties.
- 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 EWPs

↑ 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

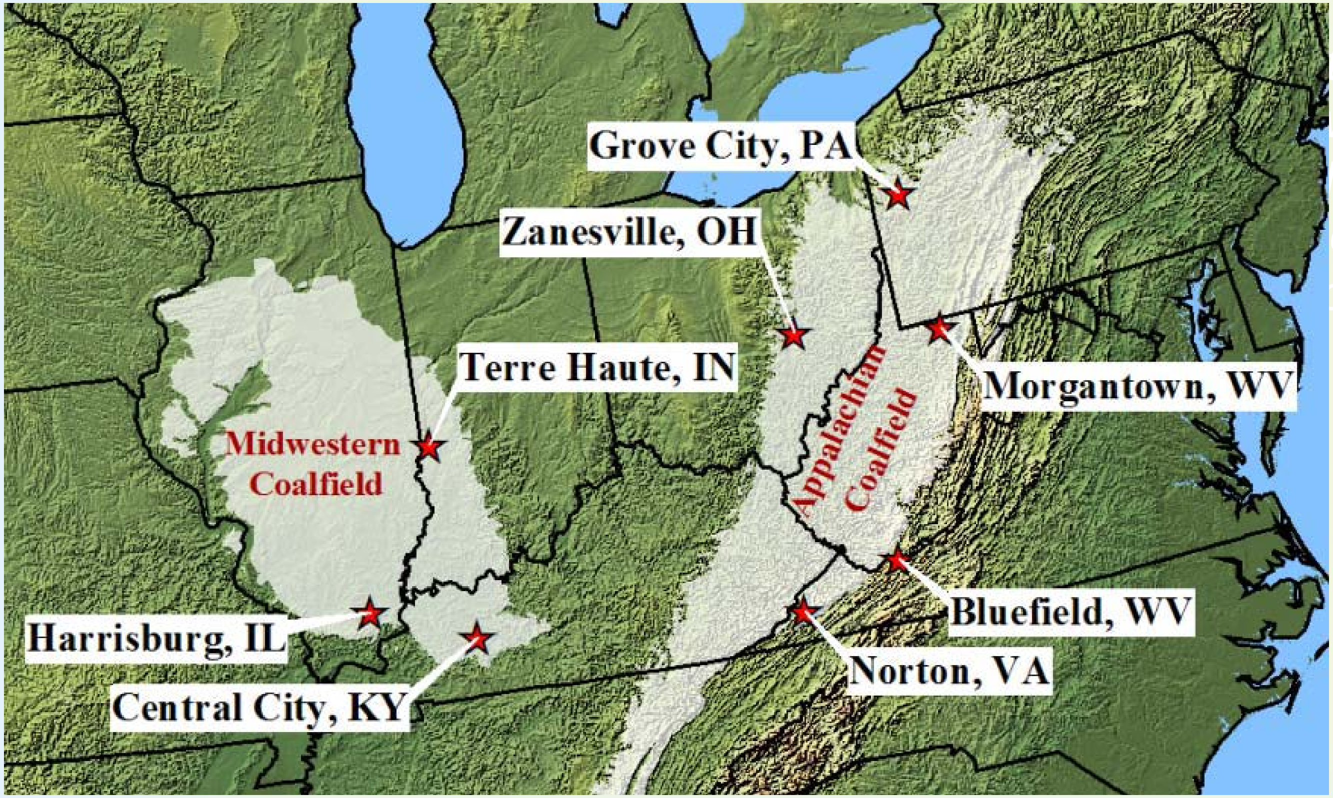

Photos: both are 8 yr old eastern white pine (EWP)

↑ 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.

Rodgrigue'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.

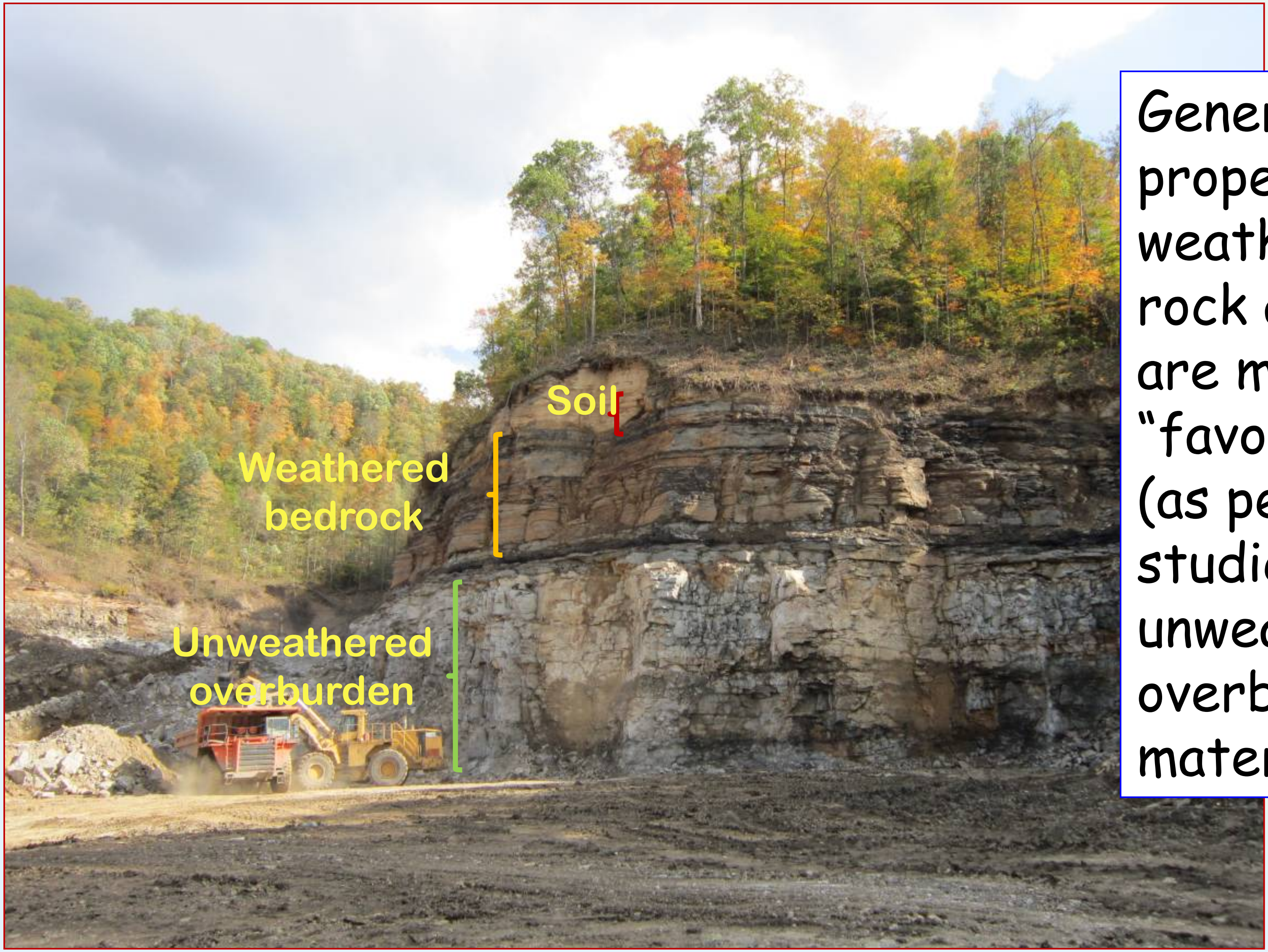
EC / soluble salts: should be low.

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


Pine Growth Variation Associated with Overburden Rock Type on a Reclaimed Surface Mine in Virginia

RED OAK SEEDLING RESPONSE TO DIFFERENT TOPSOIL SUBSTITUTES AFTER FIVE YEARS

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

WVU:
Emerson, Skousen

UKy:
Angel, Barton
Miller, Barton

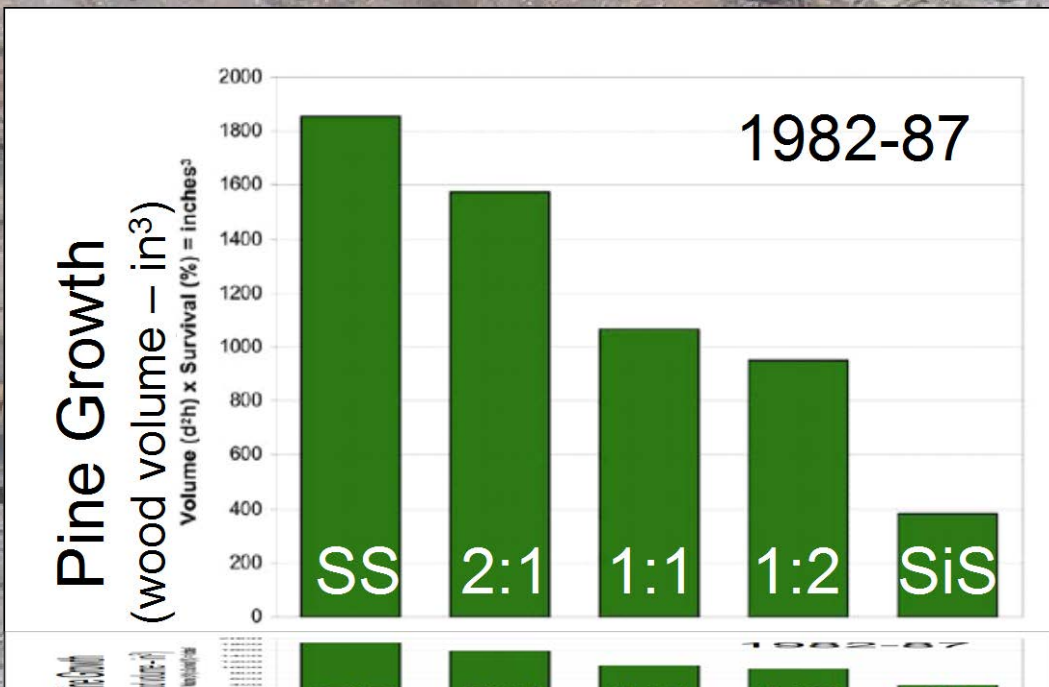
VT: Showalter, Burger (pot study)

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.



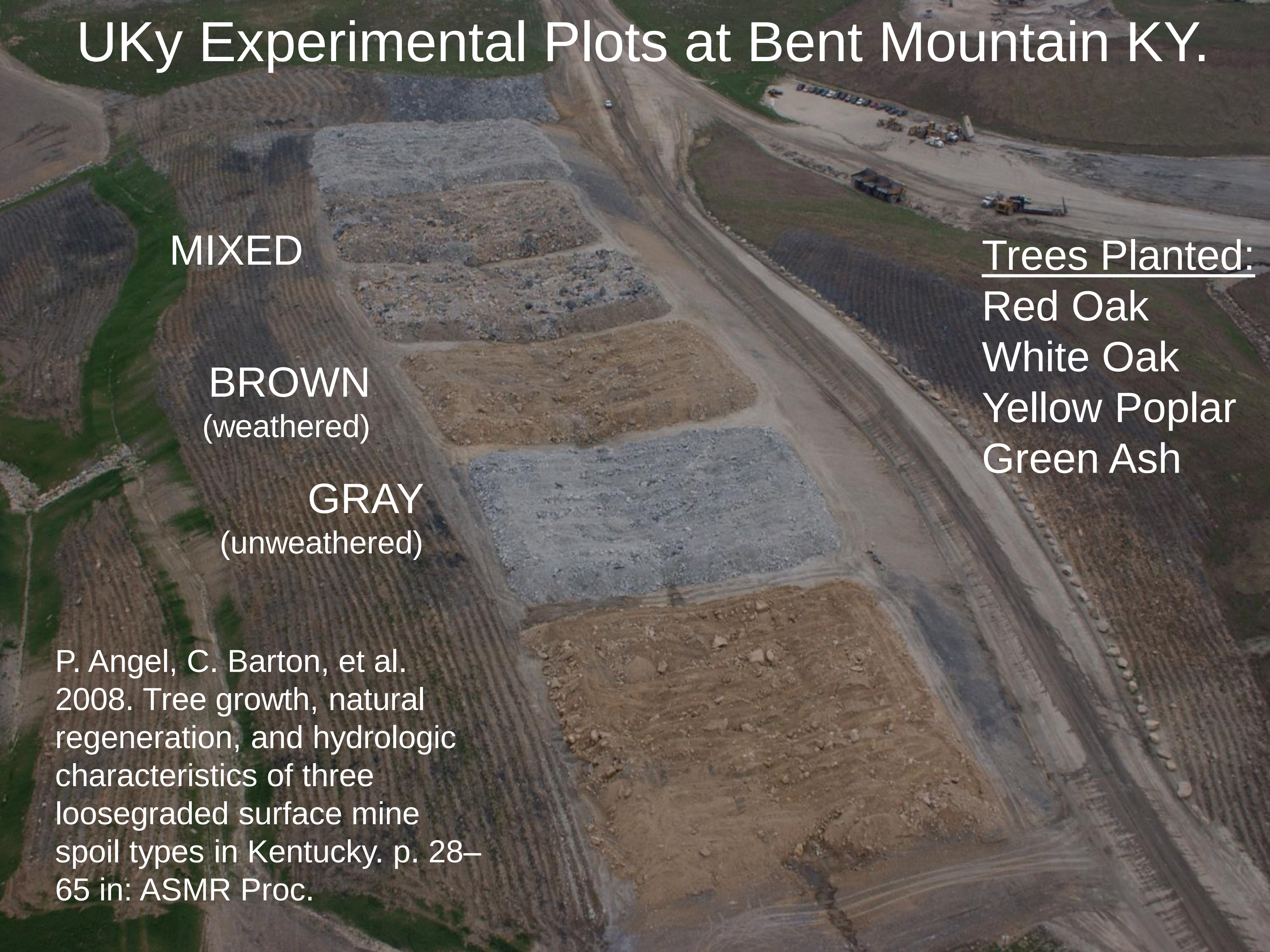
J. Torbert et al. 1990. Pine growth variation associated with overburden rock type on a reclaimed surface mine in Virginia. Journal of Environmental Quality 19:88-92.

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

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

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.

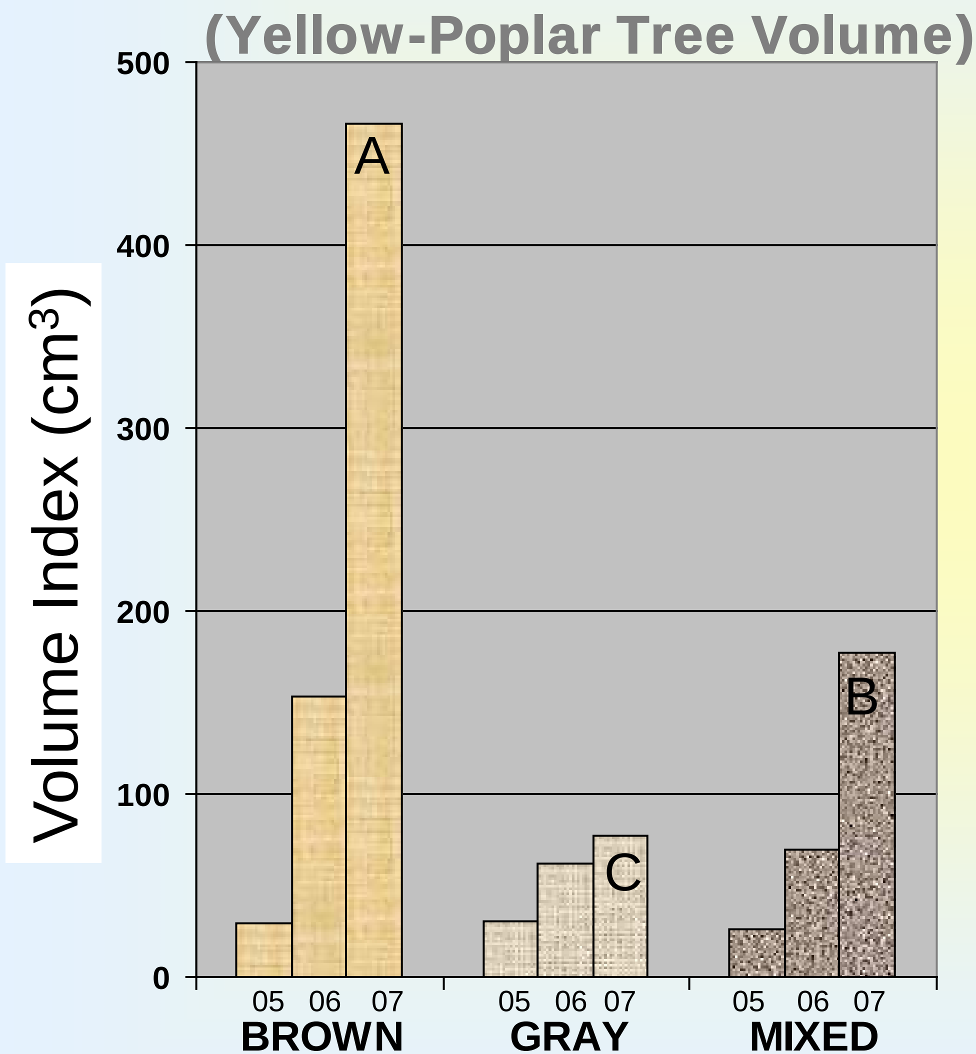
UKy Experimental Plots at Bent Mountain KY.



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



Survival 86% 88% 81%

(Brown Sandstone, 2007)

Bent Mountain Project – 2YR Seedbank Response

(Natural Regeneration)

BROWN	MIXED	GRAY
66.4% cover	5.8% cover	2.0% cover
61 species	35 species	12 species

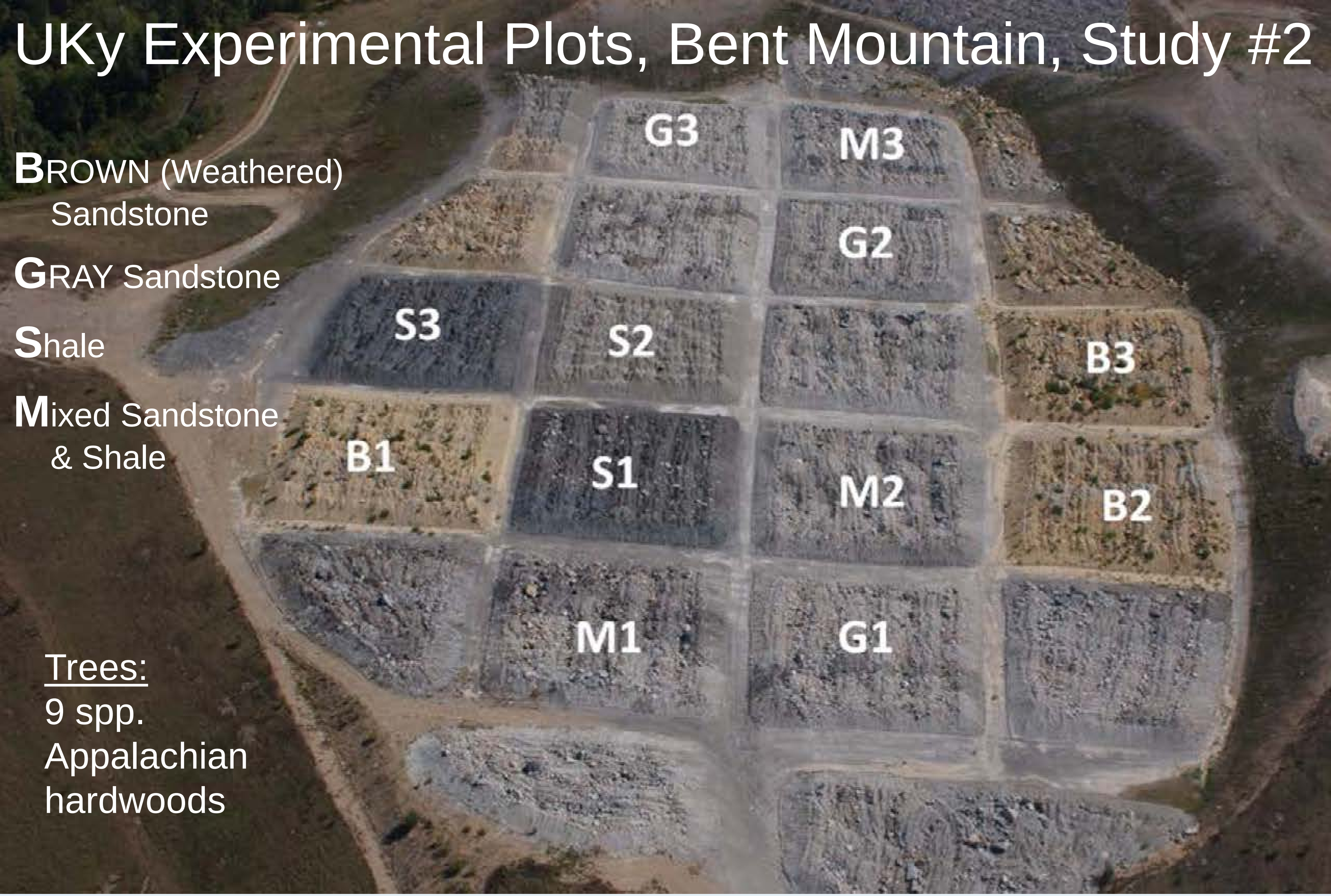
UKy Experimental Plots, Bent Mountain, Study #2

BROWN (Weathered) Sandstone

GRAY Sandstone

Shale

Mixed 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).

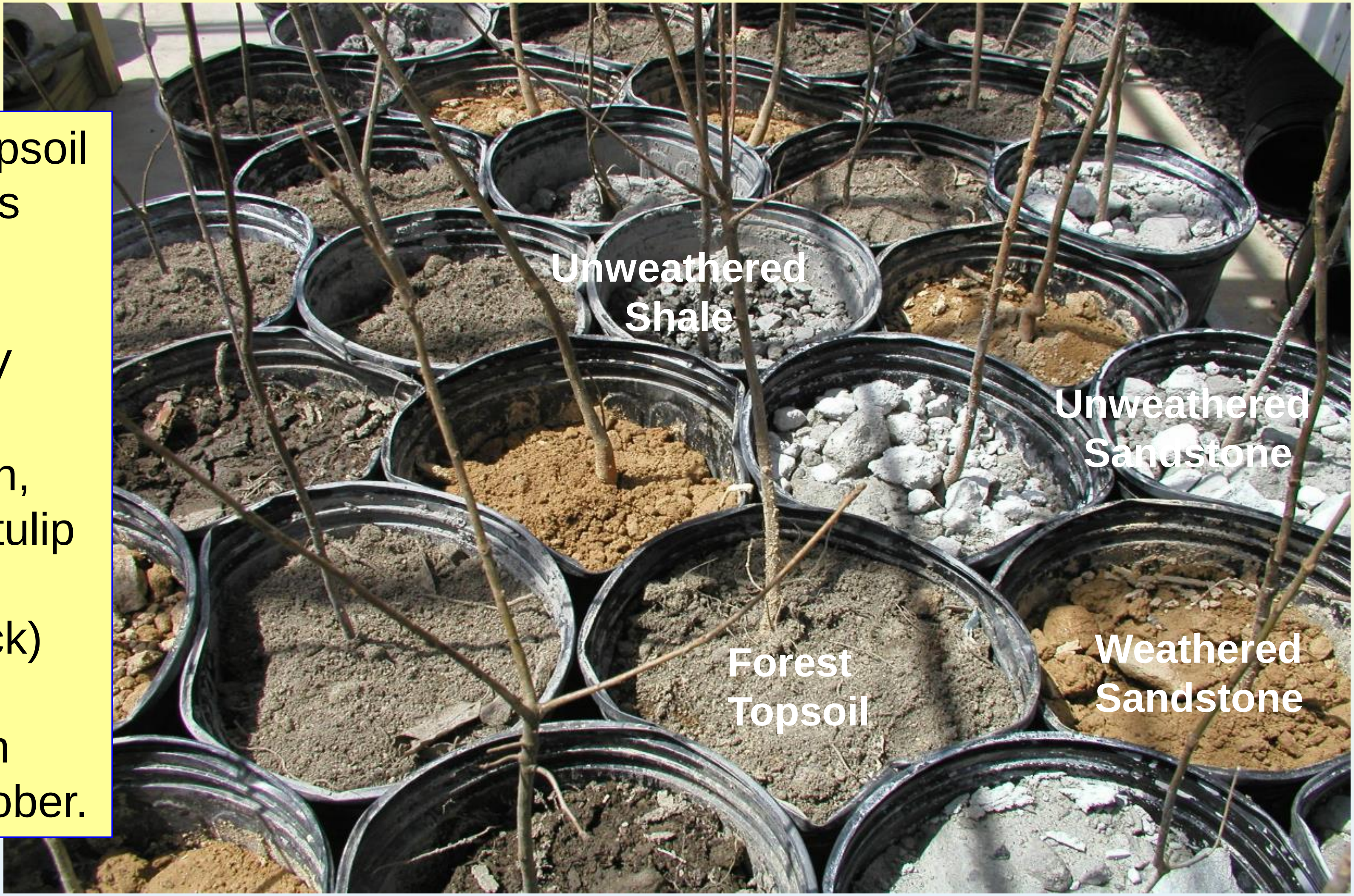
Mean tree growth was greater on weathered sandstone (94 cm) than on all other treatments (ranged from 47 – 60 cm)

Mine soil comparison in greenhouse

Forest topsoil and spoils from Pritchard Mine, WV

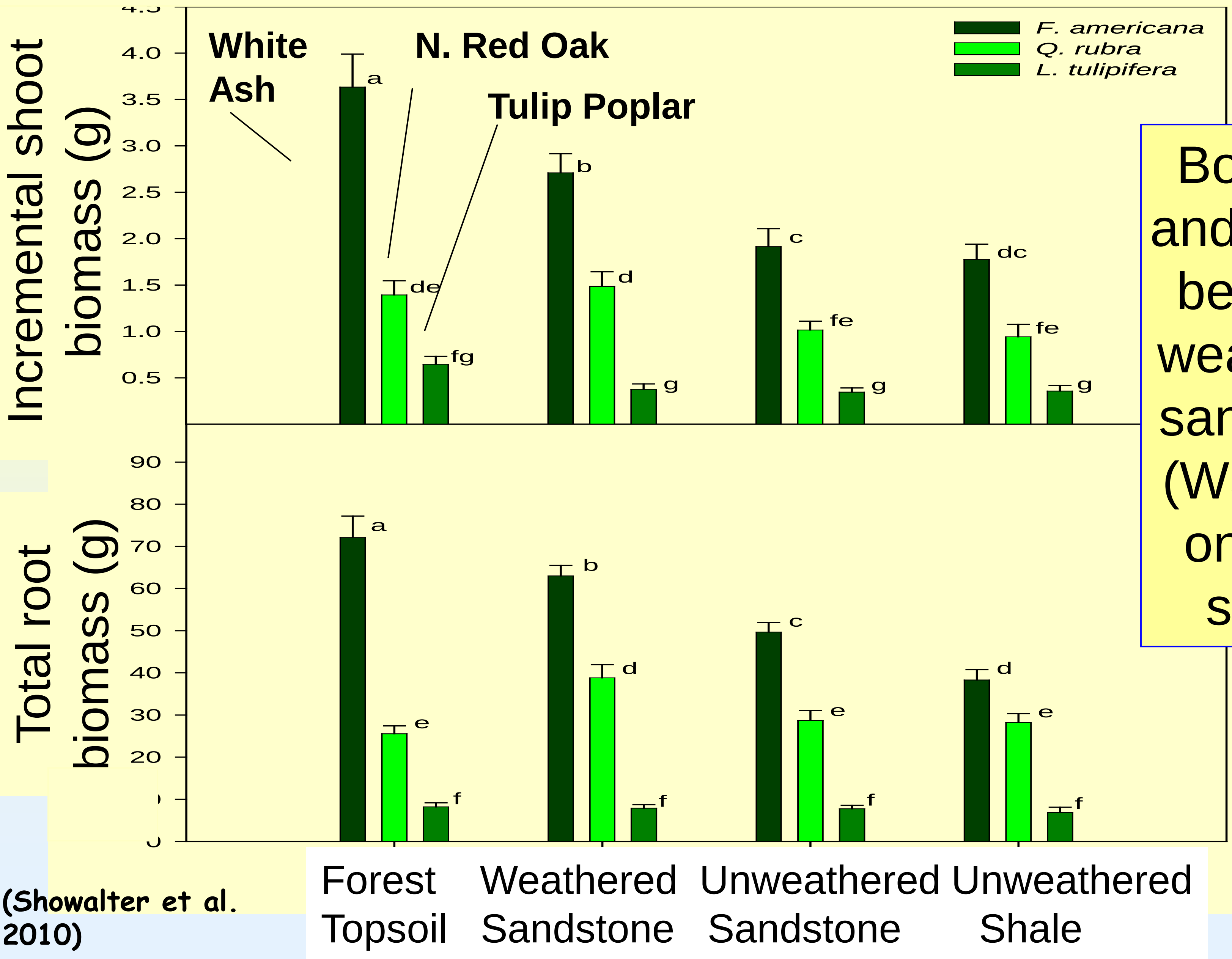
White ash, red oak, tulip poplar (2-yr stock)

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

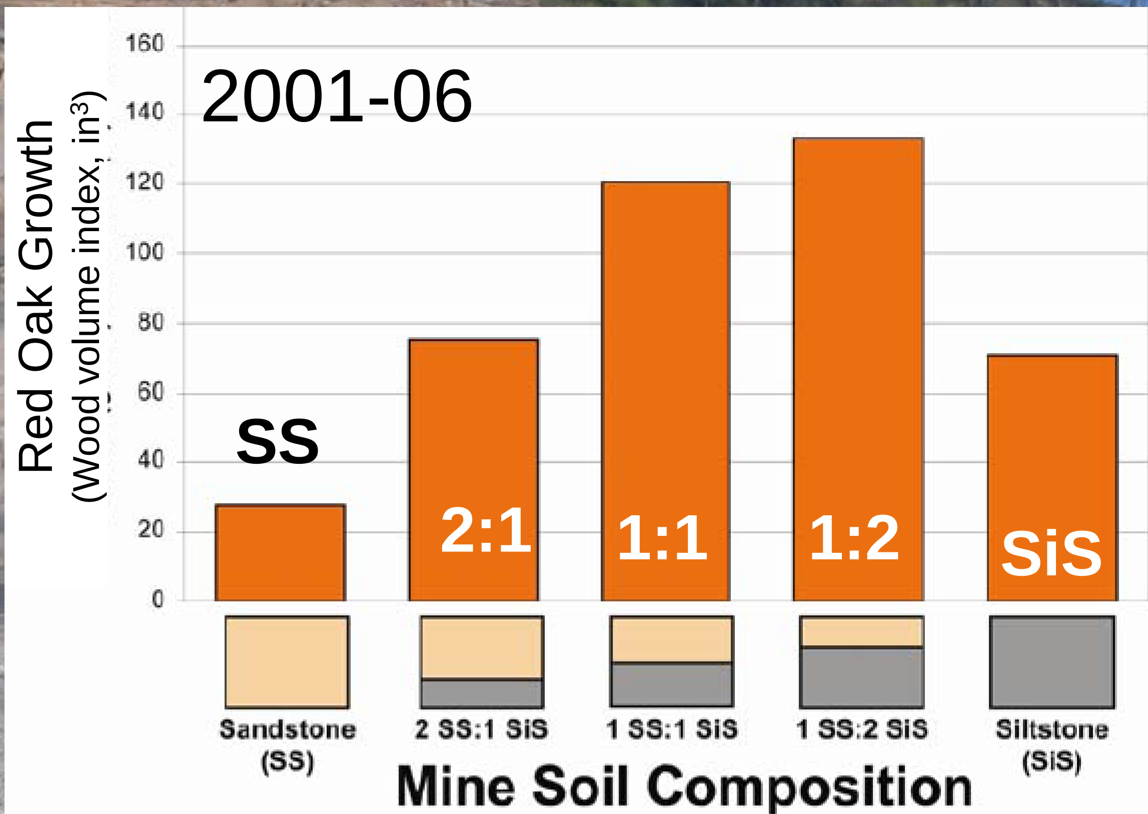
Tree growth on different spoil types



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

(Showalter et al. 2010)

(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

UKy: Angel, Barton; 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

Rodrigue, pre-SMCRA mines, 6 states

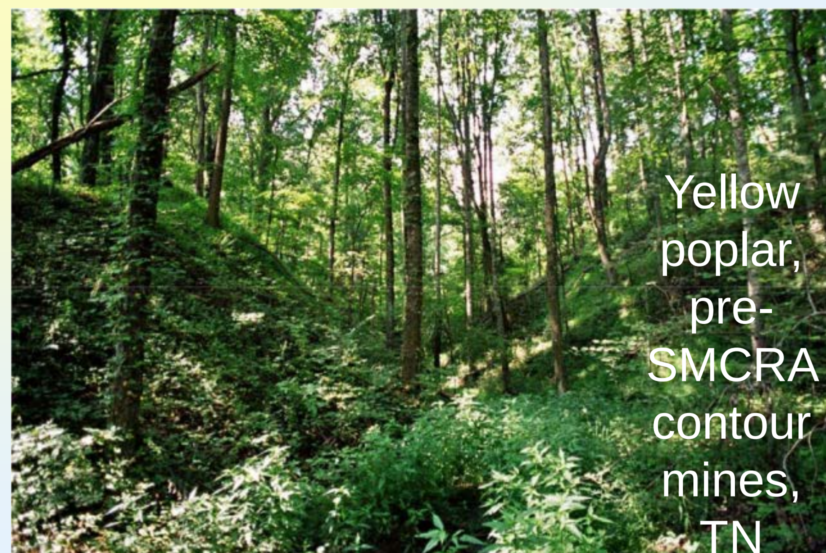
E.W. Pine, VA, SMCRA- interim

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

STARFIRE Mine

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).

J. Burger, D. Evans. 2010. Ripping compacted mine soils improved tree growth 18 years after planting. p. 55–69 in: ASMR Proc.

J. Burger, A. Fannon. 2009. Capability of reclaimed mined land for supporting reforestation with seven Appalachian hardwood species, 176–191 in: ASMR Proc.

C. Casselman, T. Fox, J. Burger. 2007. Thinning response of a white pine stand on a reclaimed surface mine in southwest Virginia. Northern J. Appl. Forestry 24:9–13.

C. Cotton. 2006. Developing a method of site quality evaluation for Quercus alba and Liriodendron tulipifera in the eastern Kentucky coal field. M.S. thesis. Univ. of Kentucky.

J. Franklin, J. Frouz. 2007. Restoration of soil function on coal mine sites in eastern Tennessee 50 years after mining. In: Proceedings, ESA and SERI Joint Meeting (Abstract).

J. Rodrigue, J. Burger. 2004. Forest soil productivity of mined land in the midwestern and eastern coalfield regions. Soil Sci. Soc. Am. J. 68:833–844.

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)

Sincere thanks to: Our many collaborators, cooperators, and research sponsors.