Survival and Growth of Hardwoods in Brown versus Gray Sandstone on a Surface Mine in West Virginia

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Surface mining in West Virginia removes the eastern deciduous forest and reclaiming the mined land to a productive forest must consider soil depth, soil physical and chemical properties, soil compaction, ground cover competition, and tree species selection. Our objective was to evaluate tree survival and growth in weathered brown sandstone and in unweathered gray sandstone. Brown and gray sandstone are often substituted when insufficient native topsoil is available for replacement. Three 2.8-ha plots were constructed with either 1.5 or 1.2 m of brown sandstone, or 1.5 m of gray sandstone at the surface. Half of each plot was compacted with a large dozer. Percent fines (<2 mm) in the upper 20 cm was 61% for brown sandstone and 34% in gray. Brown sandstone's pH was 5.1, while gray sandstone's pH was around 8.0. In March 2005, 2-yr-old seedlings of 11 hardwood species were planted. After 3 yr, tree survival was 86% on 1.5-m gray sandstone, 67% on 1.5-m brown sandstone, and 82% on 1.2-m brown sandstone. Survival was 78% on noncompacted and 79% on compacted areas. Average volume of all trees (height × diameter^2) was significantly greater on brown sandstone (218 cm^3) than gray sandstone (45 cm^3) after 3 yr. Black locust (*Robinia pseudoacacia* L.) had the highest survival (100%) and significantly greater volume (792 cm^3) than all other tree species. Survival of the other 10 species varied between 65% for tulip poplar (*Liriodendron tulipifera* L.) and 92% for redbud (*Cercis canadensis* L.), and volume varied between 36 cm^3 for white pine (*Pinus strobes* L.) and 175 cm^3 for tulip poplar. After 3 yr, brown sandstone appears to be a better topsoil material due to the much greater growth of trees, but tree growth over time as these topsoils weather will determine whether these trends continue.

Surface coal mining has disturbed about 2.5 million ha since 1930 in the United States (Paone et al., 1978; Plass, 2000). In Appalachia, the vast majority of surface mined land was originally covered by eastern deciduous forest. The earliest laws governing reclamation of surface mines were passed in Ohio, Pennsylvania, and West Virginia during the 1940s, and these laws required mine operators to register with the state and pay bonds to ensure reclamation after mining. Reclamation laws prescribed soil, subsoil, and overburden (the geologic material overlying the coal) to be used to refill the excavated area. Backfilling and leveling the land was specified, and trees and shrubs were to be planted in the regraded areas (Plass, 2000). Reclamation practices at the time were not intended to restore or replant a variety of hardwood tree species that originally inhabited the area, only to reshape the land and to plant readily available trees or shrubs. Approximately 60% of the land disturbed between 1930 and 1971 was reclaimed by backfilling with soil or overburden materials and planting some trees or grass (Ashby, 2006; Keys et al., 1971; Limstrom, 1960).

Reforestation research on surface mines began in the 1930s and reports on planting success began in the 1940s. Black locust was the most extensively studied and successful species (Brown and Tryon, 1960). Other species such as autumn olive (*Elaeagnus umbellata* Thumb.), Virginia pine (*Pinus virginiana* Mill.), red pine (*P. resinosa* Ait.), and white pine grew well in many early studies (Brown, 1962; Chapman, 1947; Mickalitis and Kutz, 1949; Minkler, 1941; Potter et al., 1955; Tryon, 1952). Potter et al. (1955) showed good survival and growth with the four pine species described above, but also found good survival with some native hardwoods (black locust, tulip poplar, red maple (*Acer rubrum* L.), and sycamore (*Platanus occidentalis* L.)). Tyner et al. (1948) found that compacted surface layers down to 45 cm created survival problems for tree seedlings, and hardwoods like oaks (*Quercus* spp.) and cherry (*Prunus* spp.) did not grow well because of rodent damage.

By 1977 state and federal legislation, The Surface Mining Control and Reclamation Act (SMCRA), encouraged establishment of grasses and legumes rather than trees (Plass, 1982; Torbert and Burger, 2000). It was reasoned that forage species (i) stabilized the surface and controlled soil erosion, (ii) established quickly and provided a quick economic return to land owners through haying or grazing of livestock, (iii) were less expensive to establish, and (iv)

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Abbreviations: ARRI, Appalachian Regional Reforestation Initiative; EC, electrical conductivity.

were aesthetically pleasing (Boyce, 1999; Vogel, 1977). SMCRA also encouraged topsoil replacement, erosion control, protection of water quality, and returning the land to its approximate original contour (Davidson et al., 1984). In addition to the above reasons, establishment of herbaceous vegetation achieved rapid ground cover and allowed partial release of reclamation bonds. The resulting landscape was often compacted due to the added vehicle traffic needed to achieve the desired slopes and due to the application of clayey topsoils. Planting trees into dense, herbaceous ground cover and compacted soils generally resulted in high tree mortality, so tree planting was largely abandoned by coal companies. Compaction of topsoil and establishment of thick ground cover have been found to be counterproductive in producing hardwood forests (Ashby, 1991; Chaney et al., 1995; Rodrigue and Burger, 2004; Torbert, 1995).

Since 2000, there has been a gradual shift by coal companies in some regions to re-establish forests on reclaimed mines (Burger and Zipper, 2002; Torbert and Burger, 2000) and this shift has been enhanced by the Appalachian Regional Reforestation Initiative (ARRI) (Angel et al., 2005).

Appalachian mountains have very thin soils (generally <15 cm) and most is lost during logging and preliminary excavation for mining. Much of the overburden in southern West Virginia consists of sandstone with minor shale inclusions. This is unglaciated terrain and a deep weathering zone has developed from 5 to 10 m in depth, which is often referred to as brown sandstone. The brown color results from oxidation of minor amounts of pyrite and siderite minerals leaving behind goethite and a base-poor, mildly acidic silicate sand matrix. Below the weathered zone, unweathered, gray sandstone has retained much of its calcite-based alkalinity and its cementing matrix. Typically only the subsoil and the brown sandstone immediately underneath the soil profile are available for salvage as "topsoil" (Smith and Sobek, 1978). Salvaging topsoil from steep slopes is expensive and dangerous, and regulations have allowed the use of "substitute" materials, which often include both weathered and unweathered geologic strata from the overburden. With larger equipment and advancements in mining technology since the passage of SMCRA, surface mining operators now remove much greater volumes of overburden to reach the coal. These greater depths to obtain coal often extend well below the oxidized strata (weathered brown sandstone) and into the unoxidized strata (gray unweathered sandstone). When placed on the surface, the unweathered gray material can undergo rapid changes in physical and chemical properties in a relatively short time span (Haering et al., 1993) and a minesoil profile can start to develop in as little as 3 yr (Sencindiver and Ammons, 2000) and form soil. Physical and chemical properties such as bulk density, percent fines, percent sandstone, pH, and nutrient concentrations change over time as these soils weather and can result in the development of a very acceptable growth medium (Bendfeldt et al., 2001).

The pH of minesoils is largely determined by their parent material and weathering conditions. Soil materials made of weathered brown sandstone tend to be more acidic (4.0–5.5) while unweathered gray sandstone materials are generally much more alkaline (7.5–8.0) (Haering et al., 2004). Soil pH can also vary greatly within a few meters. For instance, it is not unusual to find soils with acidic pH values of 4.0 close to moderately alkaline soils with pH 8.0 (Haering et al., 2004) due to uneven mixing of weathered and unweathered materials. This may be attributed to materials with high levels of calcite and/or pyrite that can change pH by several orders of magnitude with weathering (Sobek et al., 2000).

In Appalachian soils, the presence of elevated electrical conductivity (EC) values can indicate either highly alkaline or highly acidic soil (Jurinak et al., 1987; Sobek et al., 2000). Soluble salts are an influential variable in the survival and growth of tree seedlings (Davidson et al., 1984; McFee et al., 1981) and site productivity decreases with an increase in soluble salt concentration (Andrews et al., 1998; Rodrigue and Burger, 2004; Torbert et al., 1988, 1990). In one of these studies, Torbert et al. (1988) showed that finely-textured soils whose parent material consisted of mainly shales and siltstones had much higher EC than more coarse sandstone overburdens (see also Rodrigue and Burger, 2004). Soluble salt concentrations of >1–3 dS m^{-1} were found to be unfavorable for plant growth and tree survival (Cummins et al., 1965; McFee et al., 1981).

Native forest soils in the region are typically mildly acidic and often contain high concentrations of Fe and Al, and low concentrations of P, K, Ca, and Mg (Farr et al., 2008; Slagle et al., 2004). Substituting blasted rock materials for native topsoils can change the amounts of nutrients available for plant uptake (Sobek et al., 2000) and make the use of fertilizers and mulches a critical component of reclamation (Mays et al., 2000). As geologic units are placed at the surface and weather, their minerals release nutrients, which can either be held in the soil and available for plant uptake or leached.

Mine operators commonly use heavy equipment to grade the surface and spread topsoil. This creates a smooth but very dense surface soil. However, research has shown that compaction restricts infiltration, and increases runoff and erosion (Hatchell et al., 1970). Compacted surfaces also create a poor seedling growth medium by inhibiting infiltration, root growth and the ability of a soil to drain once it becomes saturated (Omi, 1986). All of these factors negatively affect tree survival and growth (Ashby, 1987; Ashby et al., 1984; Byrnes et al., 1980; Siegel-Issem et al., 2005; Torbert and Burger, 1990; Zeleznik and Skousen, 1996). Less intensive grading leaves loosened, albeit rougher, surface which enhances moisture retention and root penetration, and promotes tree growth (Phillips, 2006).

Another hindrance to successful tree establishment is competition from herbaceous vegetation (Torbert and Burger, 2000). According to SMCRA, coal operators must establish "a diverse, effective, and permanent vegetative cover of the same seasonal variety native to the area…that is capable of self-regeneration and plant succession…" and the cover must also be "capable of stabilizing the soil surface from erosion…" (Section 816.111 of SMCRA). To comply with these standards, coal operators generally establish an aggressive, dense ground cover. It is generally composed of quick-establishing perennial grasses and legumes that are established by hydroseeding with heavy fertilization and mulching. Often this ground cover consists of Kentucky-31 tall fescue (*Festuca arundinacea* Schreb), red clover (*Trifolium pratense* L.), Sericea lespedeza (*Lespedeza cuneata* L.), and other species, all of which are non-native. The resulting cov-

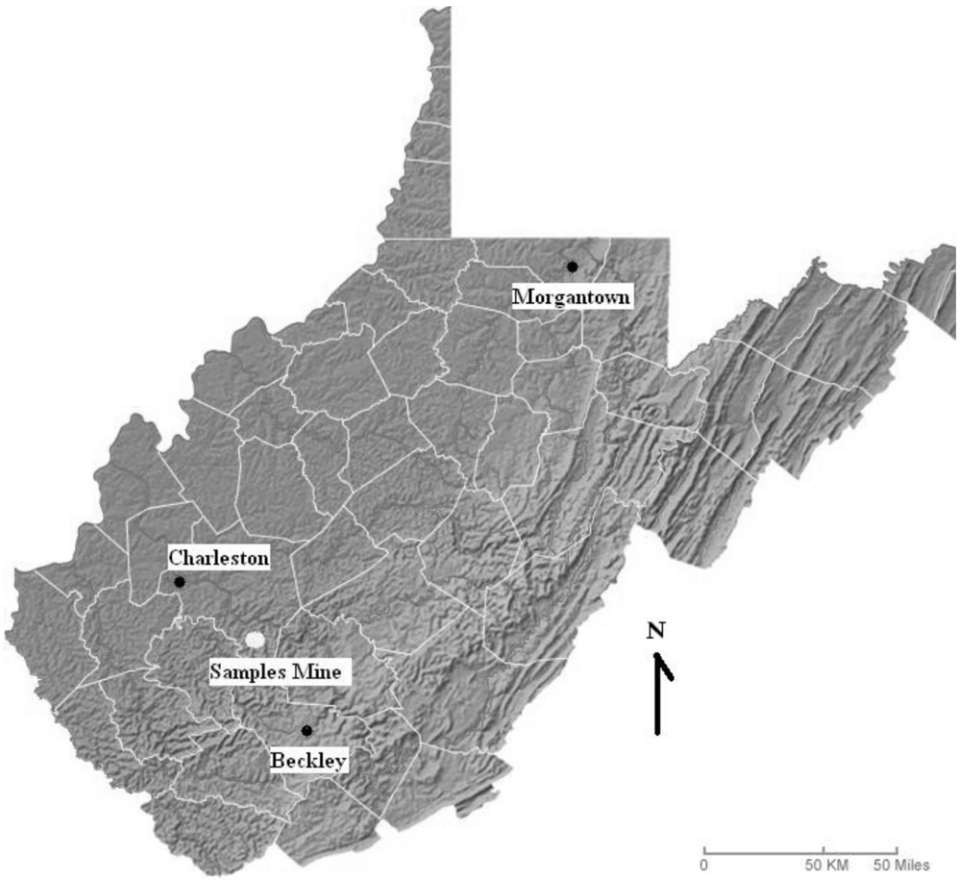

Fig. 1. Map of West Virginia showing location of major cities in the state and the location of the Samples Mine where this research occurred.

er is very dense and competitive, and this impedes the establishment of tree and shrub seedlings (Ashby, 1997; Burger and Torbert, 1990; Holl, 2002). Some annual or perennial grasses can grow much taller than the young seedlings in the early stages of development and smother the seedlings when the aerial portions die back in the winter. In addition, a heavy groundcover also provides cover for small mammals which feed on the bark and girdle trees (Skousen et al., 2007; Torbert et al., 2000). Torbert and Burger (2000) showed less-competitive herbaceous species to be a better option when seeding ground cover for reforestation sites. Redtop (*Agrostis alba* L.), birdsfoot trefoil (*Lotus corniculatus* L.), as well as other annual grasses, perennial grasses, and legumes have been found to control erosion effectively for the first year, while at the same time allowing for better establishment of native tree species (Holl, 2002).

A study was established in 2005 to test several of the major factors that hinder tree development on surface mined lands. With the help of Catenary Coal Company, we established large plots to evaluate the survival and growth of 11 hardwood tree species in gray or brown sandstone, and in compacted and uncompacted areas on each topsoil material. We also determined the physical and chemical properties over a 3-yr period of these two materials with standard soil tests.

Materials and Methods

Catenary Coal Company operates the Samples Mine in Kanawha County, West Virginia (Fig. 1). In January of 2005, three 2.8-ha plots were constructed: the first had 1.5 m of weathered brown sandstone (5B) placed on the surface, the second had 1.2 m of weathered brown sandstone (4B) placed on the surface, and the third had 1.5 m of unweathered gray sandstone (5G) placed at the surface (Fig. 2). The object was to simulate, as closely as possible, the grading and planting conditions that would pertain to a commercially-scaled reforestation project. These plots were randomly placed on a nearly level slope adjacent to one another with a 6-m buffer region separating them. After placement, one-half of each plot was compacted with a D-10 Caterpillar dozer with tracks completely covering the surface. The uncompacted plots received only one or two passes with the same dozer.

In March 2005, 11 species (Table 1) of 2-yr-old stock trees were manually planted at 2.4 by 2.4 m spacing (1680 stems per ha). The trees were not inoculated with mycorrhizae before planting, but rather had the root systems dipped in soil slurry before planting to moisten the roots. Tree species were planted in a mixed arrangement across the site. Dibble bars were used to open a hole in the topsoil, the tree roots were thrust into the hole, and the tree planter then closed the hole by pushing the soil together with his shoe; he then took a few steps and opened another hole. During the second year, the area was hydroseeded with a mix of low-competition grasses and forbs (Table 2). By the third growing season, the ground cover was still relatively sparse, providing about 50% cover.

Tree survival and volume were determined by establishing two transects (196 m long by 3 m wide) across each topsoil plot.

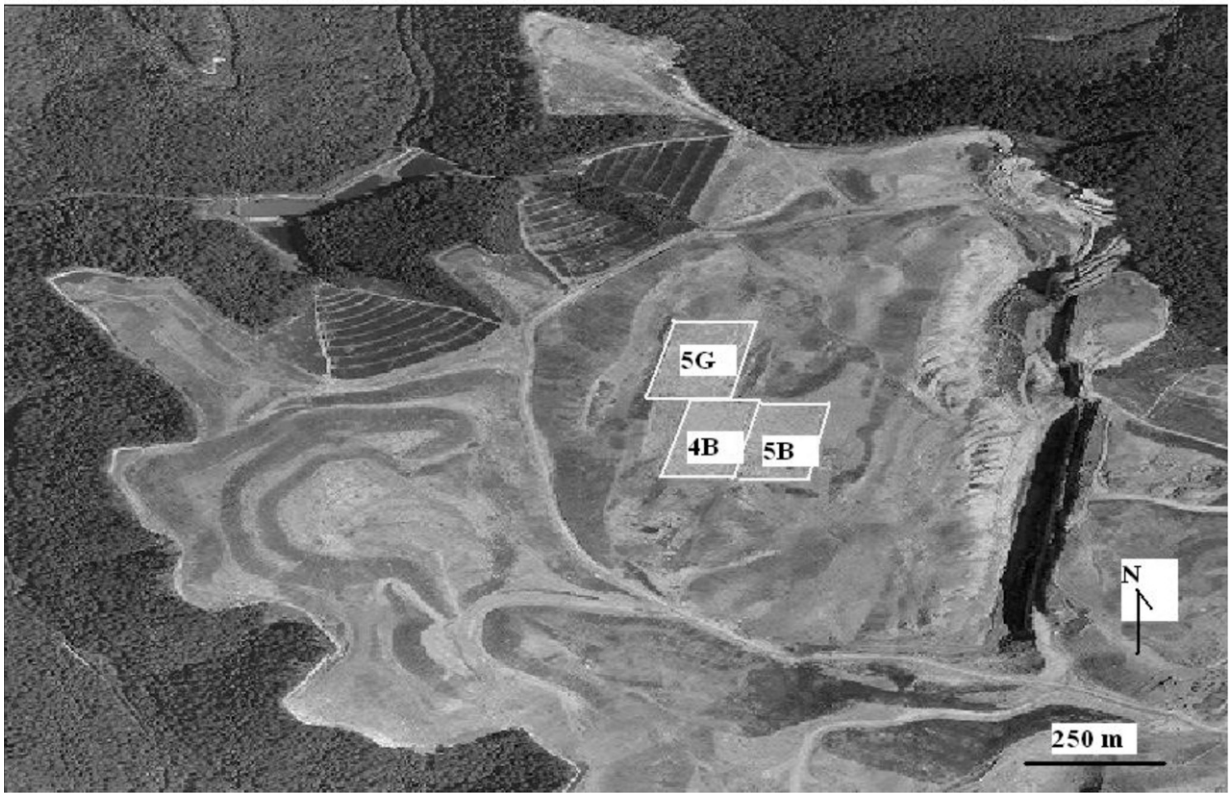

Fig. 2. Aerial photo of the three 2.8-ha demonstration plots at Catenary Coal Mine, Kanawha County, West Virginia. Half of each plot was compacted at the surface.

Table 1. Species and number of trees planted in 2005 at Catenary's Samples Mine in Kanawha County, West Virginia.

Species	No. planted	Percent of trees planted
Red oak (*Quercus rubra* L.)	3400	22
White oak (*Quercus alba* L.)	2500	16
Chestnut oak (*Quercus prinus* L.)	1250	8
White ash (*Fraxinus americana* L.)	2500	16
Tulip poplar (*Liriodendron tulipifera* L.)	1250	8
Sugar maple (*Acer saccharum* Marsh.)	1500	10
Black cherry (*Prunus serotina* Ehrh.)	465	3
Black locust (*Robinia pseudoacacia* L.)	465	3
Dogwood (*Cornus alternifolia* L.)	465	3
Redbud (*Cercis canadensis* L.)	465	3
White pine (*Pinus strobes* L.)	1250	8
Total	15,500	100

This allowed for at least three trees of each species to be sampled in each topsoil/compaction treatment. For example, red oak, the most heavily planted species, had more than 15 trees sampled in each treatment combination, while black cherry, one of the least planted trees, had three or more trees sampled per treatment. Every planted tree within the transect was identified and measured for height, and diameter was determined at 2.5 cm above the soil surface. Tree volume was determined by the formula:

$$\text{Tree volume (cm}^3\text{)} = \text{Height (cm)} \times \text{Diameter}^2\text{ (cm}^2\text{)} \qquad [1]$$

Data for tree survival and volume for each species were analyzed by a two-way ANOVA to determine significant differences between topsoil type (gray vs. brown, 1.5-m brown vs. 1.2-m brown), and compaction treatment. Since the number of trees sampled in each treatment combination was not always equal, we used Proc Mix to analyze the unbalanced data and unequal variances (SAS Institute, 2005). Interactions were also analyzed by ANOVA. Species survival and volume data were also compared among species. Volume was not normally distributed with six extreme outliers so volume data were log transformed to normalize the data.

Table 2. Species and rates of ground cover hydroseeded at Catenary's Samples Mine in Kanawha County, West Virginia.

Species	Rate
	kg ha^{-1}
Redtop (*Agrostic alba* L.)	2.2
Perennial ryegrass (*Lolium perenne* L.)	2.2
Birdsfoot trefoil (*Lotus corniculatus* L.)	11.0
Total	15.5

Soil samples were collected from the upper 20 cm at five randomly selected points along each transect in 2005, 2006, and 2007 for each topsoil-compaction treatment. These samples were weighed, then sieved to separate the soil samples into the coarse fraction (>2 mm) and the fine fraction (<2 mm). Percent sandstone was determined by using the coarse fraction and removing all the rocks and particles that were not sandstone, then weighing the sandstone fragments.

The fine fraction of the soil was extracted with a Mehlich 1 extract (0.05 mol L^{-1} HCl and 0.025 mol L^{-1} H_2SO_4, Mehlich, 1953). The resulting solution was analyzed with a PerkinElmer Plasma emission spectrophotometer for P, K, Ca, Mg, Al, Ba, Fe,

and Mn. Soil pH was determined on a 1:1 mixture with deionized distilled water with a Beckman 43 pH meter. Electrical conductivity was determined on a 2:1 soil/water mixture with a Microprocessor Conductivity Meter LF-3000 (Bower and Wilcox, 1965).

Annual soil data were analyzed by a three-way ANOVA to compare soil properties (pH, percent fines and percent sandstone) and elemental data (P, K, Ca, Mg, Al, Fe, and Mn) across topsoil, compaction treatment, and year (n = 5 for each treatment for each year). Statistical analysis showed few differences for soil properties across years within a specific topsoil-compaction treatment. Therefore, soil data within a treatment for each year (2005–2007) are shown, but significant differences were based on the overall means and variances over 3 yr of data collection (n = 15 for each treatment).

Results and Discussion

Soils

The pH of the minesoils fluctuated slightly over time (Table 3). The 5G-C treatment had a pH of around 7.6 the first year, which increased to 8.5 by the third year, while the 5G-NC treatment showed a more consistent pH of 8.3 over the 3 yr. The brown sandstone had mixed results. Both 4B plots and the 5B-NC plot had pH values between 4.3 and 5.7 over 3 yr, while the 5B-C plot had a higher pH (5.8–6.5). Average soil pH values in gray sandstone (8.2) were significantly higher than in brown sandstone (4.8–6.1). The 5B-C plot (pH 6.1) had a significantly greater pH than the other brown sandstone plots (pH < 5.0) (Table 3). Most fresh minesoils composed of sandstone have been shown to become more acidic as they weather. Some of our minesoil pHs declined as expected, some maintained constant pH, while others increased.

On all treatments, percent fines showed a decreasing trend in Year 2 (average of 47% in 2005, 36% in 2006) and then a slight increase to 52% in Year 3 (Table 3). Significantly lower fines were found in the gray sandstone compared to the brown sandstone. On gray sandstone, percent sandstone increased in Year 2 and was similar in Year 3.

While particle size attenuation is expected over time, the results may reflect eluviation of fine particles into the large voids common in gray sandstone. In Year 3, the percent fines rose slightly, which may indicate that the large pores may have begun filling up with fines in the upper portion of the profile, which may have led to an increase of percent fines in the upper 20-cm sampling region. More time will be needed to see if this trend of increasing percent fines continues. The fact that percent fines was significantly lower for gray sandstone appears to have had a negative effect on moisture retention and hence growth.

The EC values were relatively low in the minesoils, varying from 0.20 to 0.53 dS m^{-1} in 2005, and reduced further by Year 3 (Table 3). Torbert et al. (1988) found EC values of Virginia minesoils ranged from 0.30 to 1.7 dS m^{-1}, with the higher EC values being related to finely textured soils derived from shales and siltstones.

When comparing the elemental data, a few differences were found among topsoil treatments. No significant differences were found for the exchangeable bases (K, Ca, and Mg) (Table 4) even though there were quite large differences in pH among topsoils (Table 3). Phosphorus was found to be significantly higher in gray sandstone (24 mg kg^{-1}) than brown sandstone (7 mg kg^{-1}), and in most cases had up to four times more P in gray vs. brown sandstone. Phosphorus is an important element for tree survival and growth in minesoils of Appalachia (Casselman et al., 2005), and the greater P availability from the unweathered gray sandstone may promote root growth and development. Further analysis of P in these minesoils over time and its influence on tree survival and growth will be examined. There were a few other differences in elemental concentrations between the two topsoils. Aluminum and Mn were significantly higher in brown vs. gray sandstone, while Ba and Fe were reversed.

Table 3. 2005 to 2007 soil properties on two topsoil types under two compaction treatments at Catenary's Samples Mine in Kanawha County, West Virginia.

	Treatments†					
Properties	5B-NC	5B-C	4B-NC	4B-C	5G-NC	5G-C
pH						
2005	4.7	6.0	5.2	4.7	8.3	7.6
2006	5.7	5.8	4.6	4.5	8.2	8.2
2007	4.5	6.5	4.7	4.3	8.3	8.5
Avg.	5.0 c‡	6.1 b	4.8 c	4.5 c	8.2 a	8.1 a
Percent fines						
2005	53	50	48	49	36	40
2006	36	43	37	41	31	29
2007	60	64	61	59	34	34
Avg.	50 a	53 a	49 a	50 a	34 b	34 b
Percent sandstone						
2005	44	47	50	48	61	57
2006	61	55	61	58	65	67
2007	40	36	40	41	66	66
Avg.	49 a	46 a	51 a	49 a	64 a	64 a
Electrical conductivity, dS m^{-1}						
2005	0.43	0.39	0.28	0.53	0.2	0.21
2007	0.33	0.28	0.27	0.35	0.29	0.26
Avg.	0.38 a	0.34 a	0.27 a	0.44 a	0.25 a	0.24 a

† 5B-NC = 1.5-m brown sandstone noncompact.
5B-C = 1.5-m brown sandstone compact.
4B-NC = 1.2-m brown sandstone noncompact.
4B-C = 1.2-m brown sandstone compact.
5G-NC = 1.5-m gray sandstone noncompact.
5G-C = 1.5-m gray sandstone compact.

‡ Means for each element across treatments with the same letter are not significantly different at $P \leq 0.05$.

Tree Survival and Volume

Analysis of variance showed significant differences for tree survival and volume between topsoils (gray vs. brown) and among species, but not between compaction treatments (Table 5). Topsoil depths (1.2 vs. 1.5 m) were not different in tree survival but were different in volume.

Gray sandstone had significantly higher tree survival (86%) compared to brown sandstone (75%), largely due to the lower survival in the 5B-NC plot at 59% (Table 6). However, the surviving trees grew more rapidly in brown sandstone with an average volume across all trees of 218 cm^3 for brown and 45 cm^3 for gray. Topsoil depth (1.2 vs. 1.5 m) affected tree volume in the 1.2-m brown vs. the 1.5-m brown sandstone treatment (again due to the lower volume in the 5B-NC plot). It is not apparent

Table 4. Elemental concentrations on two topsoil types under two compaction treatments at Catenary's Samples Mine in Kanawha County, West Virginia.

Element		Treatments†					
		5B-NC	5B-C	4B-NC	4B-C	5G-NC	5G-C
		cmol$_c$ kg^{-1}					
K	2005	0.18	0.17	0.19	0.2	0.17	0.17
	2006	0.15	0.15	0.17	0.25	0.12	0.13
	2007	0.17	0.15	0.16	0.21	0.14	0.15
	Avg.	0.17 a‡	0.16 a	0.17 a	0.22 a	0.15 a	0.15 a
Ca	2005	1.8	2.8	2.4	2.3	2.9	3.2
	2006	2.6	2.7	1.8	1.8	2.4	2.5
	2007	2.1	2.3	1.9	1.9	2.2	2.6
	Avg.	2.2 a	2.6 a	2.0 a	2.0 a	2.4 a	2.7 a
Mg	2005	1.4	2.1	1.6	2.0	1.5	1.6
	2006	2.2	2.2	1.7	1.7	1.5	1.6
	2007	1.8	2.3	1.4	1.6	1.4	1.3
	Avg.	1.8 a	2.2 a	1.5 a	1.7 a	1.5 a	1.5 a
		mg kg^{-1}					
P	2005	10	12	11	11	31	29
	2006	9	8	3	4	22	21
	2007	4	5	4	6	20	23
	Avg.	7 b	8 b	5 b	6 b	24 a	24 a
Al	2005	119	90	125	141	40	61
	2006	108	91	131	126	31	29
	2007	111	103	108	118	29	33
	Avg.	112 a	92 a	120 a	128 a	33 b	41 b
Ba	2005	0.7	1.2	1.0	0.7	1.1	1.3
	2006	0.7	1.0	0.8	0.5	1.6	1.0
	2007	0.6	0.8	0.6	0.7	1.2	1.1
	Avg.	0.7 ab	1.0 b	0.8 b	0.6 b	1.3 ab	1.1 a
Fe	2005	71	64	95	86	211	123
	2006	86	66	71	82	194	169
	2007	79	73	76	81	168	171
	Avg.	79 b	68 b	81 b	83 b	191 a	154 a
Mn	2005	82	75	71	123	49	51
	2006	116	91	93	80	36	46
	2007	101	82	78	96	41	38
	Avg.	99 a	83 a	81 a	100 a	42 b	45 b
Zn	2005	2.5	2.5	3.7	2.6	5.7	4.4
	2006	1.9	1.5	2.0	2.2	3.9	3.2
	2007	2.4	2.1	2.6	2.3	3.1	2.9
	Avg.	2.3 a	2.0 a	2.7 a	2.4 a	4.3 a	3.6 a

† See footnote for Table 3.

‡ Means for each element across treatments with the same letter are not significantly different at $P \leq 0.05$.

why the 5B-NC treatment had the lowest average survival and volume of the four brown sandstone plots, although we visually noted this area had greater numbers of large rocks at the surface compared to the other brown sandstone plots.

By species, black locust outperformed all other species by having the highest survival (100% in all plots) and the largest average volume after 3 yr (792 cm^3) across all treatments (Tables 7 and 8). Black locust has repeatedly shown good growth and survival on minesoils (Ashby et al., 1985). White pine had the lowest survival of 65% (shared with tulip poplar) and the lowest volume across all treatments and species with only 36 cm^3 (Table 8). White pine generally does not do well during the initial years of establishment (Lancaster and Leak, 1978; Hicks, 1998). But, white pine has been extensively planted on minesoils and has shown good growth and survival, and in some cases can produce a merchantable stand of timber in 30 to 40 yr (Balmer and Williston, 1983).

Table 5. ANOVA results for tree survival and volume for topsoil types, compaction treatments, topsoil depths, and 11 planted species at Catenary Coal, Kanawha County, West Virginia.

Category		DF	Type I SS	*F* value	*P* > *F*
Brown vs. Gray					
	Survival	1	0.1978	5.97	0.0175
	Volume	1	26.37	25.7	<0.0001
Compact vs. Non-compact					
	Survival	1	0.0072	0.22	0.6424
	Volume	1	0.4784	0.47	0.4974
1.2 vs. 1.5 m Brown					
	Survival	1	0.0347	1.05	0.3102
	Volume	1	5.306	5.17	0.0266
Species					
	Survival	10	0.732	2.16	0.0421
	Volume	10	21427	7.33	<0.0001
Interactions		**DF**	**LS mean**	***P* > *t***	
Survival					
	5B-NC	5	0.754	<0.0001	
	5B-C	5	0.882	<0.0001	
	4B-NC	5	0.763	<0.0001	
	4B-C	5	0.589	<0.0001	
	5G-NC	5	0.871	<0.0001	
	5G-C	5	0.855	<0.0001	
Volume					
	5B-NC	5	1.585	<0.0001	
	5B-C	5	2.389	<0.0001	
	4B-NC	5	2.007	<0.0001	
	4B-C	5	2.151	<.0001	
	5G-NC	5	0.903	0.0045	
	5G-C	5	0.469	0.1297	

Black cherry had 70% survival (0% in 5B-NC) and the third highest volume with 171 cm^3 (Tables 7 and 8). Black cherry establishes and grows rapidly on disturbed sites (Harlow and Harrar, 1968; Hicks, 1998) and on good sites can have such rapid growth in height and diameter that it can out-compete maples and beeches (Hicks, 1998). In undisturbed native forest, black cherry can grow 1 m in height and 1.3 cm in diameter a year for the first 20 yr (Harlow and Harrar, 1968).

The three oaks (red, white, and chestnut) had between 70 and 80% survival. Average volume of all oak species was 68 cm^3, well below the average of 162 cm^3 for all species. This was anticipated as red, white, and chestnut oaks all commonly emphasize root growth over shoot growth for the first few years (Ledig, 1983). Red oak's volume was 85 cm^3, the highest of the three. Red oak is one of the fastest growing native oaks in North America and has broad site tolerances (Hicks, 1998). However, it prefers well-drained soils on north and northeast aspects (Hicks, 1998). White oak is widely distributed and it is a late-succession species which is poorly adapted to pioneer conditions such as direct sunlight and barren soils (Hicks, 1998). This was shown by white oak having the lowest volume (58 cm^3) and survival (70%) of the three oak species planted. Chestnut oak is generally found on poor quality upland sites, but it grows best in alluvial soils found on benches and in coves (Ike and Huppuch, 1968). Of the three oak species planted, chestnut oak was intermediate in both survival (76%) and volume (62 cm^3). In general and as shown in our study, the growth of all three oak species is relatively slow on these newly constructed soils (Burger et al., 2002).

Dogwood and redbud have been commonly described as early-successional species on mine sites (Burger et al., 2005). Dogwood

Table 6. Average values and significant differences for survival and growth of 11 planted species after three growing seasons at Catenary Coal, Kanawha County, West Virginia.

		Survival	Volume
		%	cm^3
Topsoil			
	Gray	86 a†	45 b
	Brown	75 b	218 a
	Compact	79 a	168 a
	Noncompact	78 a	153 a
	1.2 m depth	82 a	272 a
	1.5 m depth	77 a	104 b
Species			
	Black cherry	70 d	171 b
	Black locust	100 a	792 a
	Chestnut oak	76 cd	62 b
	Dogwood	83 bc	140 b
	Redbud	92 ab	95 b
	Red Oak	80 cd	85 b
	Sugar maple	83 bc	43 b
	Tulip poplar	65 d	175 b
	White ash	79 cd	108 b
	White oak	70 d	58 b
	White pine	65 d	36 b
Interactions			
	5B-NC	59 b	117 ab
	5B-C	75 a	212 a
	4B-NC	88 a	308 a
	4B-C	76 a	236 a
	5G-NC	86 a	34 b
	5G-C	87 a	55 b

† Survival and volume means within categories (topsoil, species, and interactions) with the same letter are not significantly different at $P \leq 0.05$.

had the third highest and redbud had the second highest average survival of all species with 83 and 92%, respectively. These species are well adapted to early-successional environments and are highly shade tolerant. They have also been found to commonly volunteer on minesoils, much like black cherry (Groninger et al., 2006; Skousen et al., 2006). Their establishment as pioneer species can help to change the environment into a mid-to-late successional environment better suited for the more valuable hardwood species.

While sugar maple had higher than average survival (83% across all treatments), it had generally poor growth (average of 43 cm^3). Sugar maple prefers moist, rich, well-drained soils, but can be tolerant of sterile soils (Harlow and Harrar, 1968). A closely related species, red maple, is a common volunteer species on minesoils and was noted at this study as well as in Brenner et al. (1984).

Tulip poplar is considered by some to be the most significant tree species in Appalachia because it has the greatest volume in the region (Hicks, 1998). Tulip poplar had the second highest volume with 175 cm^3 but was tied with white pine for lowest survival (65%). Tulip poplar is considered to be intolerant to shade and grows in the best edaphic conditions. Tulip poplar has a high growth rate when compared to red oak (Ledig, 1983), as shown by tulip poplar's high average growth in our study. Another study (DenUyl, 1962) showed similar results for tulip poplar planted in spoil banks. In the DenUyl (1962) study, tulip poplar also had the lowest survival of the 10 planted species examined, but DenUyl did not take diameter nor height measurements. Tulip poplar is a prolific sprouter and sprouts usually exceed the seedling in growth

Table 7. Percent survival of 11 planted tree species on two topsoil types and two compaction treatments after 3 yr at Catenary's Mine in Kanawha County, West Virginia.

	Treatments†						
Species	5B-NC	5B-C	4B-NC	4B-C	5G-NC	5G-C	Avg.
	%						
Black cherry	0	50	100	67	100	100	70 d‡
Black locust	100	100	100	100	100	100	100 a
Chestnut oak	60	78	79	100	83	56	76 cd
Dogwood	83	67	86	100	60	100	83 bc
Redbud	67	100	100	83	100	100	92 ab
Red oak	70	70	88	80	94	79	80 cd
Sugar maple	50	78	93	75	100	100	83 bc
Tulip poplar	60	55	83	25	91	78	65 d
White ash	60	80	84	79	73	100	79 cd
White oak	54	71	95	50	73	75	70 d
White pine	44	75	63	71	67	71	65 d
Avg.	59 b§	75 a	88 a	76 a	86 a	87 a	78

† See footnote for Table 3.

‡ Means for each species (column) with the same letter are not significantly different at $P \leq 0.05$.

§ Means for each treatment (row) with the same letter are not significantly different at $P \leq 0.05$.

Table 8. Volume ($H \times D^2$ in cm^3) of 11 planted tree species on two topsoil types and two compaction treatments after three growing seasons at Catenary Coal Mine in Kanawha County, West Virginia.

	Treatments†						
Species	5B-NC	5B-C	4B-NC	4B-C	5G-NC	5G-C	Avg.
	cm^3						
Black cherry	NA‡	180	523	93	74	155	171 b§
Black locust	213	1208	1294	1863	58	115	792 a
Chestnut oak	127	47	129	24	27	19	62 b
Dogwood	156	286	209	157	11	19	140 b
Redbud	185	69	124	100	6	84	95 b
Red oak	102	104	132	120	20	32	85 b
Sugar maple	54	90	44	16	19	36	43 b
Tulip poplar	161	101	591	52	88	59	175 b
White ash	173	109	204	103	23	33	108 b
White oak	79	50	108	45	28	38	58 b
White pine	32	86	34	27	24	10	36 b
Avg.	117 ab¶	212 a	308 a	236 a	34 b	55 b	162

† See footnote for Table 3.

‡ All black cherry trees planted in the 5B-NC treatment were dead by 2007.

§ Means for each species (column) with the same letter are not significantly different at $P \leq 0.05$.

¶ Means for each treatment (row) with the same letter are not significantly different at $P \leq 0.05$.

rate. Once established, tulip poplar grows rapidly and can sustain height growth of nearly 0.5 m per year and diameter growth of 0.6 cm per year on good sites (Beck and Della-Bianca, 1970). A concern about tulip poplar is outbreaks of the yellow-poplar weevil [*Odontopus calceatus* (Say)], which have been reported in West Virginia five out of the last 20 years (Hicks and Mudrick, 1994).

White ash requires moist and fertile conditions and prefers high levels of calcium (Schlesinger, 1990). It often grows slowly and may take up to 15 yr to reach a height of 1.5 m (Hicks, 1998). White ash average survival (79%) was similar to the average survival across all species (78%), but its average volume of 43 cm^3 was lower than the mean volume 162 cm^3 of all species. White ash can develop deep root systems but in rocky

shallow soils their root systems are shallow and spreading. Ashes are early-succession species well adapted to a mine site environment. Zeleznik and Skousen (1996) as well as Skousen et al. (2007) identified white ash as the best surviving species in their minesoil studies. Harlow and Harrar (1968) also say that ashes are known to be very tolerant at the seedling stage as they are abundant in a forest's understory. Sadly, foresters predict an almost complete demise of white ash during the next two decades due to the emerald ash borer (*Agrilus planipennis* Fairmaire.), which is spreading throughout the region and was found in Nicholas County of West Virginia in 2007.

Summary and Conclusions

Analysis of soil parameters over 3 yr showed that gray sandstone had a significantly higher pH and higher levels of P than brown sandstone. Aluminum and Mn were significantly higher in brown sandstone while Ba and Fe were higher in gray sandstone. Overall, gray sandstone had more P than brown sandstone, while the latter had a slightly acidic pH and higher moisture holding capacity due to the significantly higher fines. These soils have only been exposed to surface weathering for 3 yr and they are expected to evolve rapidly. The direction taken by soil genetic processes will determine which substrate constitutes the superior tree growth medium. The high pH and low percent fines of gray sandstone likely caused the lower initial growth of these trees compared to those in brown sandstone.

Across all species, tree survival was significantly greater on gray sandstone (86%) vs. brown sandstone (75%). Survivorship was particularly poor on the uncompacted, 1.5-m, brown sandstone treatment for reasons that are unclear. While fewer trees survived on the brown sandstone, their rate of growth was significantly greater: average of 218 cm^3 vs. 45 cm^3. Tree measurements showed that black locust was the only species with significantly greater survival and volume than the other tree species.

Based on the results after 3 yr, survival averaged 78% for all trees across all planting substrates. Volume growth was significantly greater on brown vs. gray sandstone. It is not possible, after 3 yr, to conclude which topsoil type will sustain a healthy, productive, mixed hardwood forest through its first, or succeeding rotations. It is clear that the two topsoils have very different chemical and physical properties and that their respective genetic development will determine which meets the needs for forest development on Appalachian mine sites. This project is unique in that it will compare, for many years to come, the simultaneous development of forest on two very different topsoil types in a controlled setting on a reclaimed coal mine. We will continue to monitor survival and growth of trees on these sites to evaluate soils genesis and tree species' performance.

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