SURVIVAL AND GROWTH OF NATIVE HARDWOODS ON A RECLAIMED SURFACE MINE[1]

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Abstract: Surface mining in West Virginia has been taking place for nearly a century. Most of this land was once covered in eastern deciduous forest. These diverse forests provide a variety of benefits for both humans and animals. Returning the post-mined land to a productive forest requires the consideration of many factors including, but not limited to: compaction, vegetative competition, tree species selection, substrate depth, and physical and chemical properties of the substrate. The objective of this research is to evaluate tree survival and growth in weathered brown sandstone and in unweathered gray sandstone. Three, 2.8-ha plots were constructed with varying substrates at the surface: 1) 1.5 m of weathered brown sandstone, 2) 1.2 m of weathered brown sandstone, and 3) 1.5 m of unweathered gray sandstone. Half of each 2.8-ha plot was compacted, where dozer tracks completely covered the surface, while the other half had only one pass of a dozer. Percent fines in the upper 20 cm on brown sandstone increased from 51% the first year to 61% the third year, while on the gray sandstone decreased from 38% to 34%. Percent sandstone on the brown sandstone treatment decreased from 48% to 40% from the first to the third year, while on gray sandstone it increased from 59% to 66%. Brown sandstone's pH of 5.1 stayed consistent over three years, while gray sandstone's pH was 7.9 the first year and increased to 8.4 by year three. In March 2005, 11 hardwood species were planted in each plot. After one growing season, tree survival on the non-compacted areas of each treatment was >99% across all species, whereas the compacted areas showed 88% tree survival. By year three, survival had decreased to 78% on non-compacted areas and 79% on compacted. Height and diameter for each species was obtained each year of the study. In year one there was little difference between treatments across all species (average height 38.6 cm for 1.5 m brown sandstone vs. 38.9 cm for 1.5 m gray sandstone). The equation, volume index = height x $(\text{diameter})^2$, was used to evaluate volume of the trees. Survival was also calculated for years two and three. Average volume of trees on brown sandstone was significantly greater than on gray sandstone. However, survival of trees was significantly greater on gray sandstone versus brown sandstone.

Additional Key words: substrate composition, substrate depth, compaction, tree survival, tree volume, hardwoods

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Introduction

When commercial surface mining started in West Virginia in the early 1900's, reclamation was unregulated and seldom occurred. Starting in the 1930's and 40's, coal operators were required to reclaim the land back to a suitable form. A few decades after this, laws and regulations were passed in the eastern United States that promoted seeding regraded areas with grasses and legumes, which produced a quick economic return to the land owner through livestock grazing or sale of hay. However, good maintenance practices were required to keep these areas productive.

As the acreage of disturbed land continued to increase, people became interested in reclaiming disturbed areas into productive forests. Doing so requires the consideration of many factors during initial reclamation including substrate type and depth, compaction of soil medium, ground cover type and density, and tree species selection (Torbert, 1995; Torbert and Burger, 1990; Torbert et al., 1988, 1990; Vogel, 1981). Consideration of these factors when reclaiming and planting could lead to a quicker economic return from tree harvest.

The objective of this study is to determine the effects of substrate type and depth, as well as compaction on the survival and growth of 11 tree species on a mountaintop mine in West Virginia.

Site Description

Catenary Coal Company at the Samples Mine in Kanawha County, West Virginia established three demonstration plots composed of two soil mediums (Fig. 1). In January of 2005, three, 2.8-ha (7- ac) plots were established: the first had 1.5 m (5 ft) of weathered brown sandstone (5B) placed on the surface (Fig. 2), the second had 1.2 m (4 ft) of weathered brown sandstone (4B) placed on the surface, and the third had 1.5 m (5 ft) of unweathered gray sandstone (Fig. 3) (5G) placed at the surface. Fig. 4 shows the aerial view of the plot's layout.

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

Figure 2. Brown sandstone plot after three growing seasons at Catenary Coal Mine, Kanawha County, West Virginia.

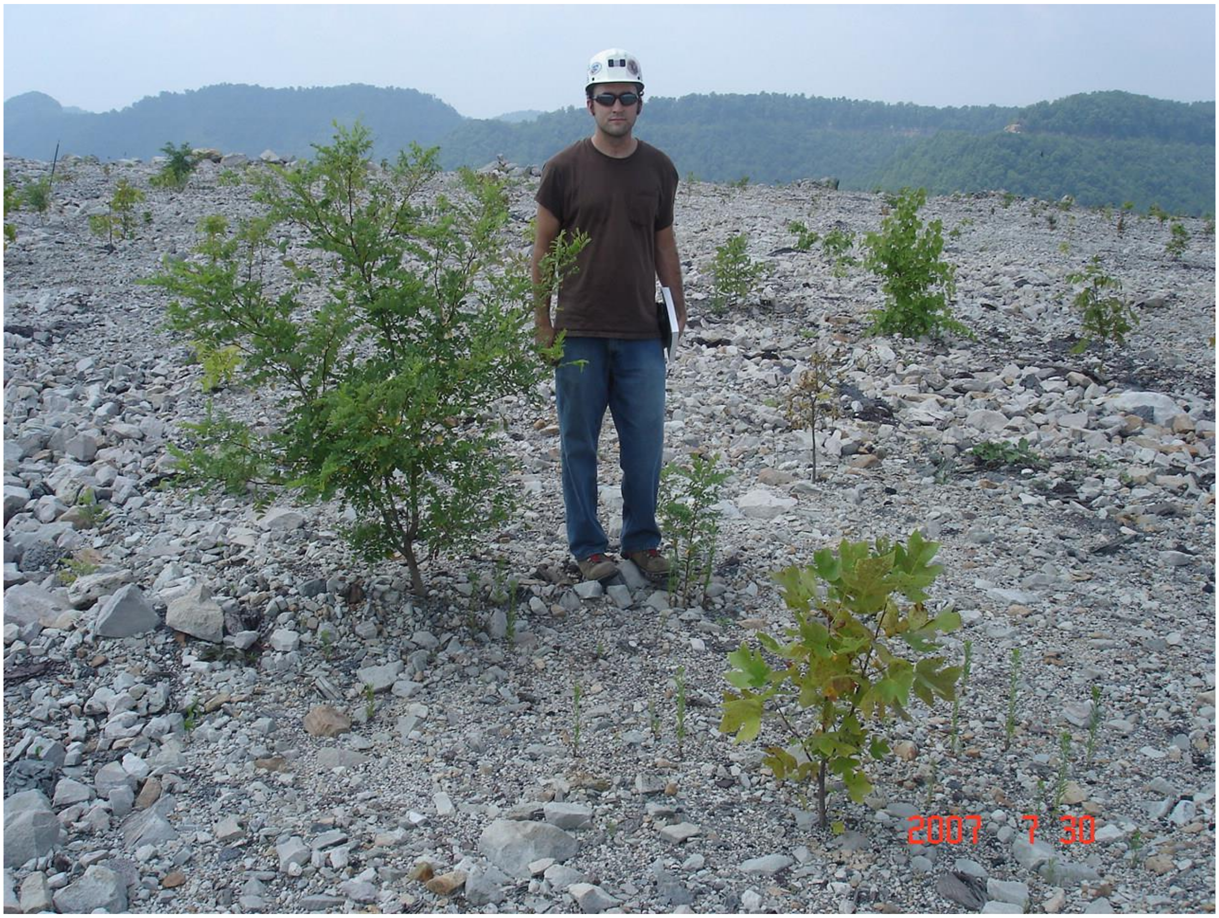

Figure 3. Gray sandstone plot after three growing season at Catenary Coal Mine, Kanawha County, West Virginia.

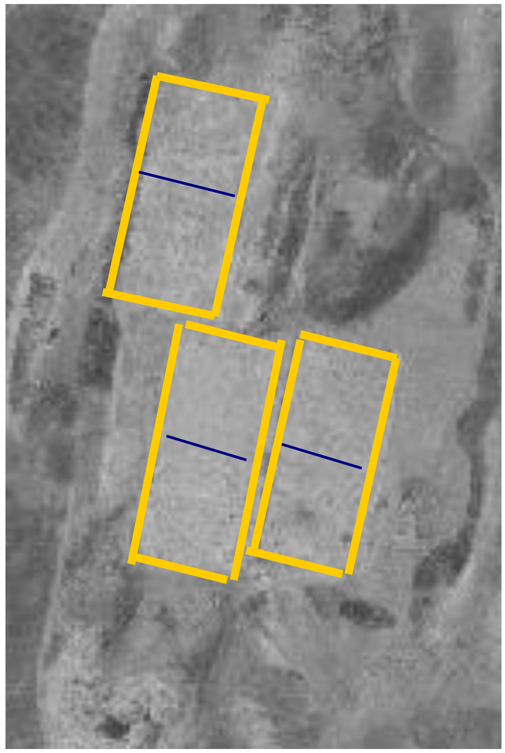

Figure 4. Aerial photo of the three, 2.8-ha demonstration plots at Catenary Coal Mine, Kanawha County, West Virginia.

These plots were constructed on a nearly level slope adjacent to one another with a 6-m (20-ft) buffer region separating them. After placement, one-half of each plot was compacted (D-10 Caterpillar dozer tracks completely covering the surface), while the other half was uncompacted with only one or two passes with the same dozer.

In March 2005, 11 species of 2-year-old stock trees were planted on these areas and some species were planted in greater numbers than others (Table 1). The trees were not inoculated with mycorrhizae before planting, but rather had the root systems soaked in water beforehand. Trees were planted by a commercial tree planting company on a 2.4 by 2.4-m (8 by 8 ft) spacing, which gives a planting density of 1680 stems per ha (680 stems per ac). Using 15-25 people, planters walked across a plot in a line and planted trees every 3 to 4 steps. Each planter had only two or three tree species in his planting bag, so the trees were not evenly planted across the site. Dibble bars were used to open a hole in the substrate, 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. White pine (*Pinus strobus*), which is being used as the indicator species, was planted at a rate of approximately 49 stems per ha, or 140 stems for each demonstration plot. As the indicator species, white pine must achieve 0.46 m of growth a year for four or more consecutive years out of a twelve year bonding period. The number of white pine is higher than the requirements in the regulations because an adequate number of trees must be available for growth increment verification and limited destructive sampling. One year after completion of tree planting, the area was hydroseeded with grasses and forbs (Table 2). The planting of these 150,000 trees on 303 ha (750 ac) (both demonstration plots and Experimental Practice areas) was done March 17-21, 2005.

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

Species	Total Number Planted	% of trees planted
Red Oak (*Quercus rubra*)	33,000	22%
White Oak (*Quercus alba*)	26,250	17.5%
Chestnut Oak (*Quercus prinus*)	11,500	7.7%
White Ash (*Fraxinus americana*)	24,750	16.5%
Tulip Poplar (*Liriodendron tulipifera*)	15,000	10%
Sugar Maple (*Acer saccharum*)	15,000	10%
Black Cherry (*Prunus serotina*)	4,500	3%
Black Locust (*Robinia pseudoacacia*)	5,500	3.7%
Dogwood (*Cornus alternifolia*)	5,500	3.7%
Red Bud (*Cercis canadensis*)	4,500	3%
White Pine (*Pinus strobus*)	4,500	3%
Total	150,000	100%

Methods

Tree survival and volume were determined by establishing two transects across each plot in an "X" pattern. Each transect was 196 m (643 ft) long and 3 m (10 ft) wide, which allowed for a sufficient number of trees of all species to be sampled. To our surprise, initial observations revealed that very few of the white pine survived. Therefore, for first year measurements (2005 growing season), the 3-m-wide transects were increased to 8.5 m (28 ft) wide in order to sample enough live white pines, while the other tree species were evaluated by using the 3-m-wide transects. Measurements for the 2006 and 2007growing seasons were done using the 3-m-wide transects because more white pine had been planted in each demonstration plot.

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

Reduced Rate of Application Species	Rate
Red Top (*Lolium perenne*)	2.2 kg/ha
Perennial ryegrass (*Lolium perenne*)	2.2 kg/ha
Birdsfoot trefoil (*Lotus corniculatus*)	11 kg/ha
Total	15.5 kg/ha

Every tree within the transects were identified and measured for height and diameter at approximately 25 mm (1 in) above the soil surface. Volume index was determined by the formula:

$$\text{Volume index (cm}^3\text{)} = \text{H (cm)} \times \text{D}^2 \text{ (cm}^2\text{)} \qquad \textbf{(1)}$$

where H was the height in cm and D was the diameter in cm approximately 25 mm (1 in) from the ground.

Soil samples were collected from the upper 20 cm (8 in) at five randomly selected points along each of the transects. This equates to five soil samples being removed for each treatment (i.e., compacted gray sandstone being one treatment). These samples were individually weighed, then sieved to separate the soil samples into the coarse fraction (>2mm) and the fine fraction (<2mm). The fine fraction was weighed to determine percent fines. 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. Soil pH was determined on a 1:1 mixture with deionized distilled water and shaken. A Beckman 43 pH meter was used to determine the pH of the mixture.

Results

Soils

The pH of the mine spoils have fluctuated through the three years of the study. There has been some conflicting research on the subject. Most mine spoils composed of sandstone have been shown to become more acidic as they weather. However, some have become more acidic and then increased in alkalinity due to continued weathering and release of carbonates (Haering et al., 2004). In this experiment, the gray sandstone did just that, with its most alkaline pH in year three of the study. The brown sandstone had mixed results. The 4B (1.2-m or 4-ft brown) sandstone plot had its most acidic reading in 2007, while the 5B (1.5-m or 5-ft brown) sandstone became more alkaline in year two and then more acidic in year three (Table 3). When comparing the average soil pH of the three year study, the gray sandstone plots were significantly higher than the brown sandstone plots. The 1.5-m brown sandstone compact plot was also significantly greater than both 1.2 m brown sandstone plots (compact and un-compact) (Table 3).

The percent fines and sandstone resulted in opposite trends. On all treatments the percent fines decreased in year two (averaged 47% in year one, 36% in year two) then increased to 52% in year three (Table 3). The percent sandstone did the exact opposite on all treatments with the exception of 5G (1.5-m or 5-ft gray) sandstone compact and non-compact. On the 5G sandstone plot, the percent sandstone increased in year two and was similar in year three. None of these changes were large enough to be significant at the $p<.05$ level.

It was expected that the gray sandstone would rapidly breakdown since this was the first time it was exposed to weathering. The initial drop in percent fines in year two showed that this may not happen. However, this decrease in percent fines could have been due to the downward movement of fines through the macro pores and large cracks common in these minesoils. In year three, the percent fines rose slightly, which may indicate that the very porous medium may be slowly building up material in the upper portion of the profile, leading to an increase of percent fines in the sampling region (upper 20 cm). More time will be needed to see if this trend of increasing percent fines will continue.

<u>Tree Survival and Volume Index</u>

By species, Black locust out performed all other species by having the largest volume after three years with 792 cm^3 (48.3 in^3) across all treatments (Table 4).

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

	Treatments[1]					
Properties	5B-C	5B-NC	4B-C	4B-NC	5G-C	5G-NC
pH 2005	6.0	4.7	4.7	5.2	7.6	8.3
pH 2006	5.8	5.7	4.5	4.6	8.2	8.2
pH 2007	6.5	4.5	4.3	4.7	8.5	8.3
Avg.	6.1 b	5.0 bc	4.5 c	4.8 c	8.1 a	8.2 a
% fines 2005	50	53	49	48	40	36
% fines 2006	43	36	41	37	29	31
% fines 2007	64	60	59	61	34	34
Avg.	53 a	50 a	50 a	49 a	34 a	34 a
% sandstone 2005	47	44	48	50	57	61
% sandstone 2006	55	61	58	61	67	65
% sandstone 2007	36	40	41	40	66	66
Avg.	46 a	49 a	49 a	51 a	64 a	64 a

[1] 5B NC = 5-foot (1.5-m) brown sandstone non-compact
5B C = 5-foot brown (1.5-m) sandstone compact
4B NC = 4-foot (1.2-m) brown sandstone non-compact
4B C = 4-foot (1.2-m) brown sandstone compact
5G NC = 5-foot (1.5-m) gray sandstone non-compact
5G C = 5-foot (1.5-m) gray sandstone compact

Table 4. Volume (H D^2 in cm^3) of 11 planted species of trees across all treatments after three growing seasons at Catenary Coal Mine in Kanawha County, West Virginia.

	Treatments[1]						
Species	5B-C	5B-NC	4B-C	4B-NC	5G-C	5G-NC	Avg.
Black Cherry	NA[1]	180	523	93	74	155	171
Black Locust	213	1208	1294	1863	58	115	792
Chestnut Oak	127	47	129	24	27	19	62
Dogwood	156	286	209	157	11	19	140
Redbud	185	69	124	100	6	84	95
Red Oak	102	104	132	120	20	32	85
Sugar Maple	54	90	44	16	19	36	43
Tulip Poplar	161	101	591	52	88	59	175
White Ash	173	109	204	103	23	33	108
White Oak	79	50	108	45	28	38	58
White Pine	32	86	34	27	24	10	36
Avg.	128	212	308	236	34	55	

[1] All Black cherry trees planted in the 5ft Brown Compact treatment were dead by 2007.

This is no surprise as Black locust has repeatedly shown good growth and survival on minesoils (Ashby et al., 1985). White pine had the lowest volume across all treatments and species with only 35.7 cm^3 (2.2 in^3) (Table 4). This result was not surprising as White pines generally do not do well during the initial few years of establishment (Lancaster and Leak, 1978; Hicks, 1998). However, White pine has been extensively planted on mine soils and has shown good growth and survival, and in some cases can produce a merchantable stand of timber in 30 to 40 years (Balmer and Williston, 1983).

Black cherry had the third highest volume with 170.8 cm^3. Black cherry is known to have rapid early growth (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). Black cherry has a large and varied natural region, but grows best on north and east facing slopes (Hicks, 1998). In undisturbed native forest, Black cherry can grow 1 m (3 ft) in height and 1.3 cm (.5 in) in diameter a year for the first 20 years (Harlow and Harrar, 1968).

Average volume of all oak species (Red, White, and Chestnut) was 68.3 cm^3 (4.2 in^3), well below the average of all species 162.3 cm^3 (5.8 in^3). 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 84.9 cm^3 (5.2 in^3), the highest of the three oak species. Red oak is one of the fastest growing native oaks in North America, has a broad site tolerance, and has been known to grow from sea-level to over 1500 m in elevation (Hicks, 1998). However, it prefers well-drained soils of concave slopes on north and northeast aspects (Hicks, 1998). Red oak has intermediate shade tolerance, but is considered less tolerant than White or Chestnut oaks (Hicks, 1998).

White oak is the most common and widely distributed of all North American oaks (Hicks, 1998). Most oaks (especially White) are late-succession species which are poorly adapted to pioneer conditions such as direct sunlight and barren soils. This was shown by White oak having the lowest volume (58.0 cm^3, 3.5 in^3) and survival (70%) of the three oak species planted (Table 5).

Table 5. Percent survival of 11 planted species of tree on three soil mediums and two compaction treatments after three years at Catenary's Mine in Kanawha County, West Virginia.

	Treatments						
Species	5B-C	5B-NC	4B-C	4B-NC	5G-C	5G-NC	Avg.
Black Cherry	0	50	100	67	100	100	70
Black Locust	100	100	100	100	100	100	100
Chestnut Oak	60	78	79	100	83	56	76
Dogwood	83	67	86	100	60	100	83
Redbud	67	100	100	83	100	100	92
Red Oak	70	70	88	80	94	79	80
Sugar Maple	50	78	93	75	100	100	83
Tulip Poplar	60	55	83	25	91	78	65
White Ash	60	80	84	79	73	100	79
White Oak	54	71	95	50	73	75	70
White Pine	44	75	63	71	67	71	65
Avg.	67	75	88	75	86	87	78

White oak seedlings and saplings are slower growing than many of the trees they are associated with, and if growing in a mixed even-age stand, White oak will be over-topped by Tulip poplar, Black cherry, Red oak, and White pine. However, due to White oak's longevity and intermediate shade tolerance, it can exist as a mid-story species until these species die back, when it will ultimately prevail as a dominant species (Hicks, 1998).

Chestnut oaks are in the White oak group, but are generally found on poor quality upland sites. However, they grow best in alluvial soils found on benches and in coves (Ike and Huppuch, 1968). Chestnut oak was the "average" oak species in this study. Of the three oak species planted, Chestnut oak was second in both volume (62.1 cm^3, 3.8 in^3) and survival (76%). Chestnut oaks are considered specialist, as they are tolerant of harsh site conditions where competition is not great. Oaks prefer to regenerate in deep, fertile soils where a diversity of microorganisms can facilitate below ground growth (Burger et al., 2002). As such, oak growth should be relatively slow on these newly constructed soils.

Dogwood and Redbud have been commonly described as early-successional species on mine sites (Burger et al., 2005). Dogwood 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 onto mine soils, much like Black cherry (Groninger et al., 2006; Skousen et al., 2006). Their establishment as pioneer species helped 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. Sugar maple grows best in moist, rich, well drained soils, but can be tolerant of sterile soils (Harlow and Harrar, 1968). It prefers to develop under heavy forest cover where shade is prevalent through the first few years of development (Harlow and Harrar, 1968). This tolerance, coupled with its slow growth rate (Hicks, 1998), explains the higher than average survival but low volume. A closely related species, Red maple, is a common volunteer species on mine soils 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 175.2 cm^3 (10.7 in^3) but was tied with White pine for lowest survival (65%). Tulip poplar is considered to be intolerant to shade and very site demanding. Aspect is considered to be the greatest controlling factor for Tulip poplar growth (Harlow and Harrar, 1968; Hicks, 1998). Tulip poplar does, however, have a high growth rate when compared to Red oak (Ledig, 1983), as shown by Tulip poplar's high average growth. 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. Neither growth, nor direct diameter or height measurements were taken in the DenUyl experiment, so growth could not be compared. Tulip poplar is a prolific sprouter and sprouts usually exceed the seedling in growth rate. These sprouts, which come from around the root collar, are even less susceptible to decay (Hicks, 1998). Once established, Tulip poplar is a vigorous grower and can sustain height growth of nearly 0.46 m/yr (1.5 ft/year) and diameter growth of 0.64 cm/yr (0.25 in/year) on good sites (Beck and Della-Bianca, 1970). A concern about Tulip poplar is large outbreaks of insects. Outbreaks of the Yellow-poplar weevil have been reported in West Virginia five out of the last twenty years (Hicks and Mudrick, 1994).

White ash is the most common ash in North America. It requires moist and fertile conditions and prefers high levels of calcium (Schlesinger, 1990). It has the capacity to be a slow growing species, and may take up to 15 years to reach a height of 1.5 m (5 ft) (Hicks, 1998). White ash seemed to be the most inconclusive of all the species in our study. Its average survival (79%) was slightly higher than the average survival across all species (78%). Its average volume of

43.2 cm^3 is lower than the mean volume 95.0 cm^3 (5.8 in^3) of all species. White ash root systems in forest soils grow deep, however in rocky shallow soils, their root systems are shallow and spreading. Ashes are early-succession species well adapted for this environment. Zeleznik and Skousen (1996) as well as Skousen et al. (2007) had White ash as the best surviving species in their 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. A concern for this species is the Emerald Ash Borer, which is spreading throughout the region and was found in Nicholas County of West Virginia in 2007.

Conclusions

Analysis of soil parameters showed that gray sandstone had a significantly higher pH than all brown sandstone plots. Percent fines and percent sandstone showed no significant differences among substrate treatments. While more significant results were expected, we propose that not enough time has elapsed for the natural weathering of these plots to make significant differences in the physical and chemical properties of these soils or effects upon the tested tree species.

The data for tree volume and survival show that after the first three years the only species that had a significantly greater volume than the other tree species was Black locust (statistical data in Tables 6 and 7). The data also support that trees on the brown sandstone had significantly greater volume than trees on the gray sandstone across all species. The interaction of sandstone type (brown or gray), compaction (compacted or uncompacted) and depth (1.2-m (4-ft) or 1.5-m (5-ft)) showed that none of the brown sandstone treatments were significantly different from each other. However, all but one of the brown sandstone treatments were significantly higher in tree volume than all the gray sandstone treatments. The only brown sandstone treatment that was not significantly different in volume was the 5B sandstone uncompact, and it was not significantly different from the 5G sandstone compact.

Table 6. Degrees of freedom, sum of squares, F value, and probabilities of survival and growth of 11 planted species at Catenary Coal, Kanawha County, West Virginia. **Interaction degrees of freedom, least squares, and probability.

Category	DF	Type I SS	F Value	Pr > F
Species				
Survival	10	.732	2.1	.0421
Volume	10	21427.3	7.3	<.0001
Substrate				
Survival	5	.679	4.11	.0028
Volume (log)	5	31.06	6.06	.0001
Brown v. Gray				
Survival	1	.1978	5.97	.0175
Volume	1	26.37	25.7	<.0001
Comp. v. Non-comp.				
Survival	1	.0072	.22	.6424
Volume	1	.4784	.47	.4974
4ft v. 5ft				
Survival	1	.0347	1.05	.3102
Volume	1	5.306	5.17	.0266

Interactions**	DF	LS mean	Pr > |t|
Survival			
5ft Brown NC	5	.754	<.0001
5ft Brown C	5	.882	<.0001
4ft Brown NC	5	.763	<.0001
4ft Brown C	5	.589	<.0001
5ft Gray NC	5	.871	<.0001
5ft Gray C	5	.855	<.0001
Volume			
5ft Brown NC	5	1.585	<.0001
5ft Brown C	5	2.389	<.0001
4ft Brown NC	5	2.007	<.0001
4ft Brown C	5	2.151	<.0001
5ft Gray NC	5	.903	.0045
5ft Gray C	5	.469	.1297

Table 7. Average values and significant differences for survival and growth of 11 planted species over three growing seasons at Catenary Coal, Kanawha County, West Virginia.

	Survival ---%---	Volume (cm^3)
Species		
BC	70 c	171 b
BL	100 a	792 a
CNO	76 bc	62 b
DW	83 abc	140 b
RB	92 ab	95 b
RO	80 abc	85 b
SM	83 abc	43 b
TP	65 c	175 b
WA	79 abc	108 b
WO	70 c	58 b
WP	65 c	36 b
Substrate		
Gray	86 a	45 b
Brown	74 b	218 a
Compact	79 a	168 a
Non-compact	78 a	153 a
4 foot	82 a	272 a
5 foot	77 a	104 b
Interactions		
5ft Brown NC	59 b	117 ab
5ft Brown C	75 a	212 a
4ft Brown NC	88 a	308 a
4ft Brown C	76 a	236 a
5ft Gray NC	86 a	34 c
5ft Gray C	87 a	55 bc

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