TREE GROWTH ON RIPPED, COMPACTED, AND SLIGHTLY COMPACTED GRAY SANDSTONE TOPSOIL SUBSTITUTE ON A SURFACE COAL MINE IN WEST VIRGINIA[1]

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Abstract: Steep topography and thin native soils characterize the coal mining regions of southern West Virginia. State and federal regulations require replacement of native topsoil during reclamation for re-establishment of a vegetative cover. Due to hazards and expense associated with collecting this thin layer of soil before mining, regulators have allowed mine operators to use substitute topsoil materials, including weathered (brown) and unweathered (gray) geologic materials for growth media. For pasture and hayland post-mining land uses, substitute materials provide suitable physical and chemical properties for establishment and growth of forages with fertilization and liming. When reforestation is the post-mining land use, regulations in West Virginia require a 1.2 m layer of native topsoil and brown weathered sandstone, but unweathered materials may be used if native topsoil quantities are insufficient. This study examined tree growth on areas where brown and gray sandstone materials were applied to the surface as growth media at the Samples Mine in West Virginia. In a study already published at this site, we found significant differences in tree growth on brown and gray sandstone plots. For this study, we selected two additional gray sandstone plots for comparison to the original brown and gray plots. The two original sites were brown sandstone compacted and gray sandstone compacted, and we added nearby plots of gray sandstone slightly compacted and gray sandstone compacted and then ripped. Average pH ranged from 7.3 to 7.9 on the gray plots compared to 5.4 on the brown plot. Tree growth on brown sandstone was more than triple that of tree growth on all of the gray sandstone plots. Mean tree volume index on the brown compacted plot was 3108 cm^3 while mean tree volume index was significantly lower on the gray compacted plot (909 cm^3), the gray slightly compacted plot (407 cm^3), and the gray ripped plot (885 cm^3). Eight years after reclamation, the gray sandstone plots, whether slightly compacted, compacted, or ripped, showed poor tree growth compared to brown sandstone. Gray sandstone has proven to be an inferior topsoil substitute for reforestation on this site.

Additional Key Words: unweathered gray sandstone, tree volume index, reclamation, reforestation, weathered brown sandstone

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Introduction

Since the enactment of the Surface Mining Control and Reclamation Act (SMCRA) in 1977, more than 600,000 ha of land have been deforested in the eastern United States for the purpose of surface coal mining (USDI OSM, 2012). West Virginia is one of the top coal producing states in the U.S., second only to Wyoming. Overall, West Virginia produced 139 million Mg (metric ton) of coal in 2012 from both underground and surface mining operations. In 2012, there were 232 active surface mines in West Virginia in 24 counties which produced 48 million Mg of coal (West Virginia Coal Association, 2012).

The Surface Mining Control and Reclamation Act was developed and enacted because of growing concerns about environmental and safety issues with surface mining. SMCRA mandates performance standards for coal operators to meet before, during, and after mining operations including restoring the land to its approximate original contour (AOC), minimizing disturbances to the hydrologic balance, reclaiming the land in a timely manner, and establishing a permanent vegetative cover (Public Law 95-87, 1977). In the past, many coal operators found that planting a variety of grasses and legumes was the fastest and most economical way to re-establish a permanent vegetative cover to meet bond release requirements. Recently however, regulatory agencies and reclamation scientists have encouraged operators to re-establish native hardwood trees on reclaimed surface mines.

The Appalachian Regional Reforestation Initiative (ARRI), a collaboration of the Office of Surface Mining (OSM) and Appalachian state agencies and university researchers, encourages mine operators to plant more hardwood trees, which enhances wildlife habitat, promotes soil and water conservation, increases timber value, and provides an economically valuable post-mining land use for the landowner (Burger, 2009; Larkin et al., 2008). A recent study found that restoring mined land to forests with productivity levels equal to or greater than pre-mining production has great potential to sequester atmospheric CO_2 (Amichev et al., 2008). The ARRI Statement of Mutual Intent recommends using the current five-step Forestry Reclamation Approach (FRA) technology. The five FRA steps are (Burger et al., 2005):

1. create a suitable rooting medium for tree growth;
2. loosely grade the topsoil or topsoil substitute;
3. seed a tree compatible ground cover;
4. plant early successional tree species and commercially valuable crop trees; and

5. use proper tree planting techniques.

These techniques are intended to increase survival and growth rates of trees, increase overall productivity, and promote natural colonization and succession of native plants and wildlife communities (ARRI, 2012; Zipper et al., 2011a).

The designation of forestry and commercial forestry post-mining land uses in West Virginia requires the placement of 1.2 or 1.5 m (4 or 5 feet) of native topsoil and weathered brown sandstone on the surface. This performance standard was established in the West Virginia surface mining regulations to optimize the growth of commercially valuable trees and to re-establish a forest ecosystem. Natural soils are often hard to recover or are diminished during mining preparations (timbering, road, and drilling construction), and are difficult to be saved, stockpiled, and redistributed during reclamation to a sufficient depth required by the regulations (Torbert et al., 1990; Emerson et al., 2009). Therefore, coal operators in Appalachia must make use of topsoil substitutes to achieve required depths of soil material. In West Virginia, the predominant overburden rock type is sandstone; as either brown sandstone, which is weathered and is often moderately acidic, or gray sandstone, which is unweathered and is often slightly- to moderately-alkaline (Emerson et al., 2009).

Studies have shown that selecting the appropriate material from the overburden to create mine soils is important when forestry is designated as the post-mining land use. Finely textured soils that develop from unweathered siltstone and shale contain elevated levels of soluble salts, which can negatively impact the growth and survival of tree seedlings (Torbert et al., 1988; McFee et al., 1981). Torbert et al. (1990) reported that sandstone-derived mine soils produced five times more stem volume than siltstone-derived mine soils. Showalter et al. (2010) reported that weathered sandstone was more conducive to native hardwood tree growth than unweathered sandstone or unweathered shale. It was concluded that the lower pH and higher water retention of the weathered sandstone were the major contributors to better tree growth. Working on a West Virginia mine site, Emerson et al. (2009) found that tree growth and volume were five times higher after three years on brown sandstone than on gray sandstone. On the same West Virginia mine site, Wilson-Kokes et al. (2013a) found tree volume index to be ten times greater on brown sandstone (3,853 cm^3) than on gray sandstone (407 cm^3) after eight years. Similar findings were shown on another site in West Virginia with tree volume index on brown (3,316 cm^3) and gray sandstone (818 cm^3) substitutes after six years (Wilson-Kokes et al., 2013b).

When reclaiming lands to a forestry post-mining land use, highly compacted mine soils can diminish the success of reforestation efforts (Burger, 1999). Soil compaction can result in root restriction, reductions in soil nutrient and water movement, and poor aeration (Brady and Weil, 2002). Some studies have reported bulk densities on reclaimed mine soils to be as high as 1.84 Mg m^{-3} (DeLong et al., 2012). In natural forest soils, many hardwood tree species experience root growth limitations at bulk densities of 1.4 Mg m^{-3} for clayey soils and 1.55 Mg m^{-3} for loamy soils (Coder, 1998). Tyner et al. (1948) reported that compacted surface layers down to 45 cm in mine soils created survival problems for tree seedlings and some grasses during dry periods. Another study found that seedling growth of northern red oak (*Quercus rubra* L.) and scarlet oak (*Quercus coccinea* Muench.) was severely hindered by soil compaction (Jordon et al., 2003). In particular, they reported a decrease in seedling height and total dry matter (roots, stems, and leaves). Minimizing soil compaction on surface mines through decreased grading improved the survival and height of tulip-poplar (*Liriodendron tulipifera* L.), northern red oak, white oak (*Quercus alba* L.), and eastern white pine (*Pinus strobus* L.) (Angel et al., 2006).

In an effort to ameliorate the effects of compaction, researchers ripped a compacted mine soil and found that ripping significantly improved tree growth in Kentucky (Burger and Evans, 2010). Ashby (1996) reported that percent survival, height, and diameter at breast height (DBH) of northern red oak and black walnut (*Juglans nigra* L.) were significantly greater on ripped mine soils in Illinois compared to non-ripped mine soils. A similar study reported higher percent survival and tree height for native hardwood tree species on ripped mine soils (Ashby, 1997). Skousen et al. (2009) found that ripping reclaimed grasslands to 1 m in depth improved survival and growth of black cherry (*Prunus serotina* Ehrh.), red oak, tulip-poplar, white oak, and black walnut. The FRA recommends avoiding compaction of soils during reclamation and only lightly grading the soil surface when forestry is the assigned post-mining land use because of the known detrimental effects of soil compaction.

The objective of this study was to compare tree growth on three unweathered gray sandstone plots with varying compaction levels and on a compacted, weathered brown sandstone plot. This study uses the tree and soil data from a previously published paper and compares it to two additional gray sandstone plots. Soil chemical properties and herbaceous ground cover percentage on the new plots were also compared to the old plots.

Methods and Materials

The Samples Mine is located approximately 50 km south of Charleston, WV (38°5’28″ N, 81°26′37″ W) and is owned by Patriot Coal and operated by the Catenary Coal Company. Originally, three plots were established in 2005, each measuring 2.8 ha and composed of brown sandstone and native topsoil (BSS) to a depth of at least 1.2 m and gray sandstone (GSS) to the same depth (Emerson et al., 2009). Each of these plots was slightly compacted with several passes of a bulldozer. Because of very poor tree growth on the gray sandstone plot after eight years (Wilson-Kokes et al., 2013a), two additional gray plots were selected to compare tree growth to the original brown and gray plots. The original gray plot (GSS) was slightly compacted, while the two new gray sandstone plots were compacted (GCP) and compacted and then ripped (GRP) (Table 1 and Figure 1). All gray materials for these plots were taken from similar unweathered geologic strata at the site. Bulk density measurements were not made at plot establishment, but were determined five years later on the slightly compacted plots brown and gray sandstone (DeLong et al., 2012). Both sites had a similar bulk density (1.7 to 1.8 Mg m^{-3}), which is nearing the level when plant roots have difficulty penetrating and expanding in the soil. We did not measure bulk density on the two new gray plots, but our observation when taking soil samples was that the soils in these two plots were similar in compaction levels to the original plots.

Table 1. Soil treatments at Catenary Coal’s Samples mine in Boone County, WV.

Treatment	Abbreviation
Brown sandstone compacted	BSS
Gray sandstone slightly compacted	GSS
Gray sandstone compacted	GCP
Gray sandstone ripped	GRP

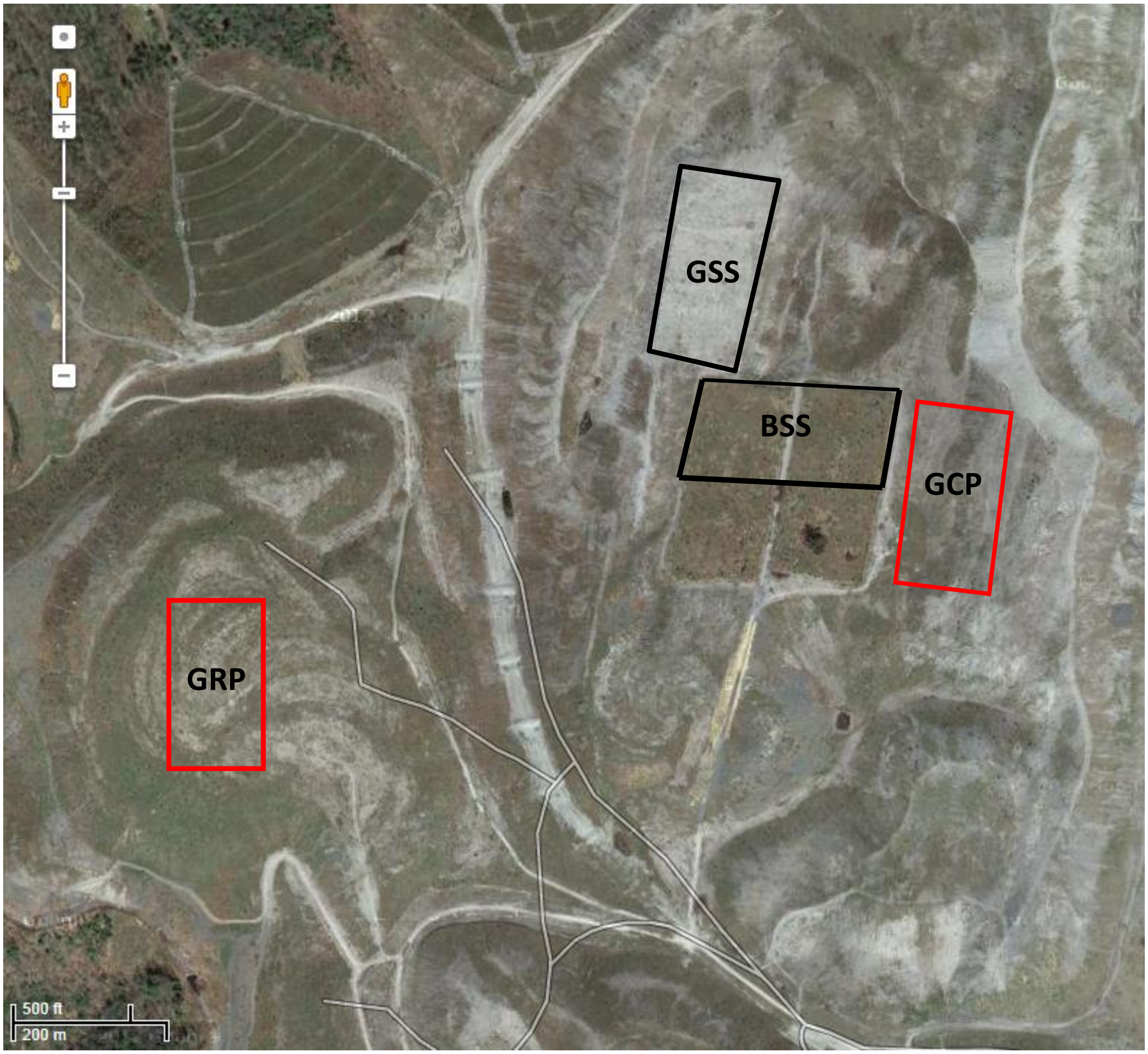

Figure 1. Locations of the four reforestation plots in relation to each other. The brown compacted plot (BSS) was between the gray slightly compacted (GSS) and gray compacted (GCP) plots, while the gray ripped plot (GRP) was farther away at Catenary Coal's Samples mine in Boone County, WV (Google Maps, 2012).

In 2005, eleven species of two-year-old tree seedlings were professionally planted on all plots (Table 2). Planting density was similar among plots (2.4-m spacing) and species were distributed relatively similar across sites. In the fall of 2007, the plots were hydroseeded with a mixture of tree compatible herbaceous vegetation (Table 3) at a rate of 15.4 kg ha^{-1}. At the time of seeding, a rate of 440 kg ha^{-1} of 10–10–10 N–P_2O_5–K_2O fertilizer was applied according to FRA recommendations.

Table 2. Species of trees planted in 2005 at Catenary Coal's Samples mine in Boone County, WV.

Species	***Scientific Name***
Red oak	*Quercus rubra* L.
White oak	*Quercus alba* L.
White ash	*Fraxinus americana* L.
Sugar maple	*Acer saccharum* Marsh.
Chestnut oak	*Quercus prinus* L.
Tulip-poplar	*Liriodendron tulipifera* L.
White pine	*Pinus strobus* L.
Black cherry	*Prunus serotina* Ehrh.
Dogwood	*Cornus alternifolia* L.
Eastern Redbud	*Cercis canadensis* L.
Black locust	*Robinia pseudoacacia* L.

Table 3. Species and rates of ground cover hydroseeded in 2007 at Catenary Coal's Samples mine in Boone County, WV.

Species	Rate
	kg ha^{-1}
Redtop (*Agrostis gigantea* Roth)	2.2
Perennial ryegrass (*Lolium perenne* L.)	2.2
Birdsfoot trefoil (*Lotus corniculatus* L.)	11.0
Total	15.4

Tree growth was determined in August 2012 by identifying and measuring every tree in two 2.7 m wide by 195 m long transects in an "X" pattern across each of the 2.8 ha plots. Tree height was measured to highest live growth and tree stem diameter was measured approximately 2.5 cm above the soil surface. Tree growth was assessed using the following formula (Emerson et al., 2009):

$$\text{Tree Volume Index (cm}^3\text{)} = \text{Height (cm) x Stem diameter (cm}^2\text{)}$$

Soil samples were collected in June 2012 to a depth of 15 cm from five randomly selected points along the two transect lines within each plot (10 samples per plot). Soil samples were air-dried and sieved to pass through a 2 mm screen. The soil material passing through the screen (fine soil fraction) was used to determine pH, extractable nutrients, and electrical conductivity. Soil pH was determined with a 1:1 mixture in DDI water using a Fisher Scientific Accumet pH meter model 915 (Thermo Fisher Scientific Inc., Pittsburgh, PA). Electrical conductivity (EC) was determined using a 1:2 mixture comprised of 5 g of soil and 10 mL of DDI water using a Mettler Toledo S230 EC meter (Mettler-Toledo International Inc., Columbus, OH). Extractable nutrients were determined using the Mehlich 1 extracting solution (0.025 N H_2SO_4 + 0.05 N HCl). The extracted solution was analyzed for extractable K, Ca, Mg, P, Fe, Al, manganese, and Zn using a Perkin Elmer Optima DV 2100 emission spectrophotometer (Perkin-Elmer Corp., Norwalk, CT).

In August 2012, percent ground cover was evaluated within a 1 m^2 quadrat. The quadrat was placed at 20 random locations within each plot along transect lines. Percent live herbaceous cover, litter cover, live tree cover, bare soil, and rocks were estimated to the nearest 5%.

Tree data were analyzed using one-way ANOVA by plot (BSS, GSS, GCP and GRP). Tukey's Honest Significant Difference (HSD) test was used to separate means at the level $p < 0.05$. Tree-volume-index data contained unequal variances so volume data were log transformed to equalize the variances. Soil data were analyzed by one-way ANOVA by plot for pH, EC, extractable nutrients, and percent fines. Tukey's HSD test was used to separate means at the level $p < 0.05$. Percent ground cover data were analyzed using a one-way ANOVA to compare cover types (herbaceous, tree, bare soil or rock, water, and total cover) by plot for 2012. Tukey's HSD test was used to separate means at $p < 0.05$. All statistical analyses were performed using the statistical program R (R Development Core Team, 2012).

Results and Discussion

Soil

Soil pH was significantly greater on the three gray sandstone plots compared to the brown sandstone plot. The mean soil pH for the gray sandstone compacted (GCP) and ripped (GRP) plots was 7.3 and 7.4, respectively, compared to 7.9 on gray sandstone slightly compacted (GSS) plot. The brown sandstone slightly compacted (BSS) had an average pH of 5.4 (Table 4). Although there was some variability in average pH values among gray sandstone plots, the mean pH values fell within or slightly below measured unweathered sandstone materials in the Appalachian coal region, as did the mean pH of the brown sandstone plot. Several studies reported that unweathered gray sandstones fell between 7.5 and 8.0 while weathered sandstones ranged from 4.5 to 6.0 (Angel et al., 2008; Haering et al., 2004; Thomas and Skousen, 2011).

Electrical conductivity (EC) was 0.08 dS m^{-1} on GCP and 0.12 dS m^{-1} on GRP, compared to 0.05 dS m^{-1} and 0.04 dS m^{-1} on GSS and BSS, respectively (Table 4). All EC values were <0.20 dS m^{-1}, well below the level at which sensitive species such as sugar maple and white pine experience reduced tree growth and survival. Soil EC values >1 dS m^{-1} can have detrimental effects on plant growth (McFee et al., 1981; Whiting et al., 2010). The average percent fines on GRP (76%) was statistically similar to the percentage of fines measured on the BSS plot (73%). However, the percent fines on GSS (30%) and GCP (41%) plots were significantly less than on the other two plots (Table 4). The significantly greater percent fine soil on the GRP plot was most likely caused by the ripping action during the reclamation process, since Miller et al. (2010) found that gray sandstone rocks exhibited a high durability in a slake-durability test and were highly resistant to weathering during the freeze-thaw test. Zipper et al. (2011b) reported that soils derived from gray sandstone would continue to have a high percentage of coarse fragments as they age and that many hard-grained sandstones have slow decomposition rates.

Table 4. Soil properties of samples from four sandstone plots at Catenary Coal's Samples mine in Boone County, WV.

	Treatments §			
Properties	GSS	GCP	GRP	BSS
pH	---------------	su	---------------	
	7.9^{a} *	7.4^{a}	7.3^{a}	5.4^{b}
EC	---------------	dS m^{-1}	---------------	
	0.05^{a}	0.12^{a}	0.08^{a}	0.04^{a}
Fines	---------------	%	---------------	
	39^{b}	30^{b}	76^{a}	73^{a}

§ see Table 1 for treatment descriptions.
* means for each treatment combination within rows with the same letter are not significantly different at $p < 0.05$.

Sandstone type significantly affected extractable nutrient concentrations. The highly weathered nature of the brown sandstone resulted in significantly lower concentrations of Mg, Ca, and P compared to the unweathered gray sandstone (Table 5), while the Al concentrations in brown sandstone were higher than those in the gray sandstone plots. Extractable Al, K, and Zn concentrations were significantly different among the three gray sandstone plots. Average Al concentration on GRP was 149 mg kg^{-1} compared to 79 and 100 mg kg^{-1} on the GSS and the GCP plots, respectively (Table 5). The increase in extractable Al on GRP may be due to the higher percentage of fines and ultimately greater surface area. Average extractable K concentrations for GCP and GRP ranged from 0.18 to 0.55 $cmol_c\ kg^{-1}$, respectively, while the GSS plot had the lowest value at 0.05 $cmol_c\ kg^{-1}$ (Table 5). The low levels of K in GSS may be due to leaching (Bradshaw, 1997). However, it is also possible that the GRP and GCP plots had higher concentrations of K due to phyto-cycling (Haering et al., 1993; Mahendrappa et al., 1986). Zinc concentrations were lower on the GRP and GCP plots (5 to 10 mg kg^{1}) than on the GSS plot (16 mg kg^{-1}, Table 5). Overall, the GCP and GRP plots had higher extractable levels of many of the measured nutrients than the GSS plot.

Table 5. Soil properties from four sandstone plots at Catenary Coal's Samples mine in Boone County, WV.

Element	Treatments §			
	GSS	GCP	GRP	BSS
	------------------------------$cmol_c\ kg^{-1}$------------------------------			
Mg	6.4^{a} *	8.6^{a}	8.4^{a}	4.5^{b}
K	0.05^{c}	0.18^{b}	0.55^{a}	0.44^{a}
Ca	8.7^{b}	13.2^{a}	12.4^{ab}	5.9^{c}
	------------------------------$mg\ kg^{-1}$------------------------------			
Al	79^{c}	100^{c}	149^{b}	306^{a}
Fe	223	214	322	143
Mn	189^{ab}	242^{a}	272^{a}	146^{b}
P	183^{b}	273^{a}	162^{b}	58^{c}
Zn	16^{a}	10^{ab}	5^{b}	9^{ab}

§ see Table 1 for treatment descriptions.

* means for each treatment combination within rows with the same letter are not significantly different at $p < 0.05$.

Ground cover

Total vegetative cover was significantly higher on the BSS plot (74%) than on the gray sandstone plots (Table 6). Among the gray sandstone plots, average total vegetative cover was 36 to 47% on the GCP and GRP, respectively, compared to a meager 11% on GSS (Table 6). It is unknown why the GSS plot had such a low percentage of herbaceous ground cover. The difference between percent herbaceous cover on brown sandstone and gray sandstone plots may be due to the lower pH and greater fine soil amounts of the brown sandstone. The predominant forage species in the hydroseed mix was birdsfoot trefoil and it produced more than 50% of the total ground cover on the brown plot. Birdsfoot trefoil is best established at a pH range of 6.0 to 6.5 but will tolerate moderately acidic soils (5.5) and marginally tolerate alkaline soils (8.0) (USDA NRCS, 2013; Hannaway and Myers, 2004).

Table 6. Mean ground cover on four sandstone plots in 2012 at Catenary Coal's Samples mine in Boone County, WV.

	Treatments §			
Cover	GSS	GCP	GRP	BSS
	--------------------	%	--------------------	
Herbaceous	7^{c} *	32^{b}	40^{b}	65^{a}
Litter	0^{b}	3^{a}	5^{a}	3^{a}
Tree	4	1	2	6
Total Cover	11^{c}	36^{b}	47^{b}	74^{a}
Bare/Rock	89^{a}	64^{b}	53^{b}	26^{c}

§ see Table 1 for treatment descriptions.
* means for each plot within rows with the same letter are not significantly different at $p < 0.05$.

Trees

Average tree volume indices (TVI) for the four sandstone plots were significantly different at $p < 0.05$ (Table 7). The average TVI on BSS was significantly greater (3108 cm^3) than the average TVI measured on the three gray plots (Table 8). There were no significant differences in average TVI among the gray plots, although the average TVI for GCP and GRP ranged from 885 to 909 cm^3 while the TVI of GSS was 407 cm^3 (Table 8). Further, the average tree height on BSS was

137 cm, which was higher than 83 to 91 cm on GCP and GRP, which again was higher than the average height of 70 cm on GSS (Table 8).

Previous studies have shown that average tree height and volume were greater on weathered brown sandstone than unweathered gray sandstone (Showalter et al., 2010; Angel et al., 2008; Emerson et al., 2009). Angel et al. (2008) reported that average tree height on brown sandstone (66 cm) was significantly greater than average tree height on gray sandstone (35 cm) after 3 years. Showalter et al. (2010) attributed better tree performance on brown sandstone to lower pH and higher percentage of fines. In this study, it is possible that the significantly greater herbaceous cover on the GCP and GRP plots had a positive influence on tree growth. While aggressive herbaceous vegetation has been shown to out-compete tree seedlings for nutrients, water, and solar energy when seeded at high densities (Fields-Johnson et al., 2010), the reverse has been demonstrated when tree-compatible species such as birdsfoot trefoil (*Lotus corniculatus* L.) and ladino clover (*Trifolium repens* L.) are seeded. They can benefit tree seedling growth by reducing evapotranspiration, shading the soil surface, increasing nitrogen concentrations in the soil, and increasing the soil water holding capacity by adding organic matter to the soil via root decay (Franklin et al., 2012). Vogel (1973) reported that tree growth on legume-dominated plots exceeded tree growth on grass-dominated plots in Kentucky after the fourth growing season. After four years, Virginia pine (*Pinus virginiana* Mill.) grown on legume-dominated plots was, on average, 30 cm taller than Virginia pine grown on grass-dominated plots.

Table 7. ANOVA results for mean tree volume and mean height on four Sandstone plots at Catenary Coal's Samples mine in Boone County, WV.

Category	DF	Sum of Squares	F value	P > F
Tree volume index	3	217	21.21	<0.001
Tree height	3	34346	22.34	<0.001

Table 8. Mean tree volume index and height on four sandstone plots at Catenary Coal's Samples mine in Boone County, WV.

	Treatment §			
	GSS	GCP	GRP	BSS
Volume Index (cm^3)	407^{b} *	909^{b}	885^{b}	3108^{a}
Height (cm)	70^{c}	83^{bc}	91^{b}	137^{a}

§ see Table 1 for treatment descriptions
*means for each volume and height within columns with the same letter are not significantly different at $p < 0.05$.

Due to planting strategy, not all tree species were represented similarly in each plot as measured by our transects. Table 9 shows the distribution of tree species within each plot and Table 10 shows average tree volume index for individual species within each plot.

White ash was the only species, which had an adequate number of live specimens in each plot (> 20) for comparison. The TVI for white ash was almost identical on the GSS (523 cm^3) and GRP (530 cm^3) plots. The TVI on BSS was twice these values at 1231 cm^3 (Tables 9 and 10). The GCP plot had a mean tree volume index for white ash of only 298 cm^3, which was about half that found on GSS and GRP.

Table 9. Distribution of tree species in our transects on four sandstone plots in 2012 at Catenary Coal's Samples mine in Boone County, WV.

	Treatments §				
Species	GSS	GCP	GRP	BSS	Total
Black cherry	1	6	1	---	8
Black locust	8	8	21	50	87
Dogwood	4	---	---	4	8
Redbud	3	---	2	2	7
Red oak	28	25	6	22	81
Sugar maple	4	---	8	5	17
Tulip-poplar	12	5	22	7	46
White ash	21	24	28	28	101
White oak	14	25	8	26	73
White pine	5	2	2	11	20
Total	100	95	98	155	448

§ see Table 1 for treatment descriptions

Table 10. Mean tree volume index of tree species in 2012 on four sandstone plots at Catenary Coal's Samples mine in Boone County, WV.

	Treatments §				
Species	GSS	GCP	GRP	BSS	Average
	---------------------------------------cm^3---------------------------------------				
Black cherry	1981	149	289	---	395
Black locust	338	7664	2407	4771	3934
Dogwood	1064	---	---	973	1019
Redbud	837	---	1127	1400	1177
Red oak	366	468	217	2260	1327
Sugar maple	82	---	71	596	336
Tulip-poplar	388	78	285	535	413
White ash	523	298	530	1231	842
White oak	164	187	1112	3797	2068
White pine	146	146	874	4256	2282
Average	407	909	885	3108	

§ see Table 1 for treatment descriptions

With time, tree growth on the GRP plot may surpass tree growth on the GCP and GSS plots. According to Burger and Evans (2010), who studied the effects of ripping on tree growth 18 years after reclamation, tree growth on ripped plots surpassed the growth of trees on non-ripped plots but the effect was not discerned until that second measurement 18 years after planting. The higher percentage of fines could increase the plant-available water in the soil which would positively influence the site's productivity (Rodrigue and Burger, 2004). Skousen et al. (2009) found that black walnut seeds had a significantly greater establishment and survival on a ripped surface mine in West Virginia vs. a non-ripped treatment on the same site. At another surface coal mine in eastern Kentucky, Burger and Evans (2010) found that tree survival and tree volume were greatly improved by ripping. However, while ripping helps alleviate some of the physical limitations associated with traditional reclamation processes, compaction should be avoided whenever possible (Burger and Evans, 2010).

Conclusions

Analysis of soil chemical and physical properties showed that pH and EC were not significantly different between three gray sandstone plots. However, percent fines was significantly greater on the GRP plot compared to the GSS and GCP plots. The BSS plot had a significantly lower pH than the gray sandstone plots. Overall, the GCP and GRP plots had higher extractable nutrient concentrations than the GSS plot. In general, the BSS plot had lower extractable nutrient concentrations than the three gray plots, probably due to a higher level of weathering.

This study showed no significant difference between the three gray sandstone plots with respect to TVI, although the tree height on the GSS plot was less than that on the GCP and GRP plots. Tree growth on BSS outperformed tree growth on all gray sandstone plots, which is consistent with other studies of tree growth on brown and gray sandstone. While there were minor differences among the gray sandstone plots, the results of this study reinforce that brown sandstone is a more suitable rooting medium than gray sandstone for hardwood tree growth.

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