Soil Properties and Hardwood Growth Six Months After Planting on Brown and Gray Sandstone Soils at the Fola Mine in Clay County, West Virginia

FINAL REPORT

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In Fulfillment of the Project
HARDWOOD TREE GROWTH USING THE FORESTRY RECLAMATION APPROACH IN WEST VIRGINIA

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26 July 2010

Abstract

The forestry reclamation approach has become a widely accepted practice in the Appalachians for developing a forestry post mining land use. This approach requires the placement of 1.2 meters of uncompacted, weathered brown sandstone and pre-mining top soil or the best available material as a substitute, which is typically unweathered gray sandstone. To demonstrate the effectiveness of these two types of substrates as growth media, eight 0.8-ha plots were constructed; two brown sandstone, two gray sandstone, and four mixed. After construction, plots were planted with a mix of commercially valuable hardwood species. Six months after planting, tree growth was recorded for approximately 10% of the planted trees. Soil samples from 0 - 15 cm and 15 - 30 cm below the soil surface were collected and analyzed for % fines, pH, EC, P, K, Ca, Mg, Fe, Al, and Mn. Overall, gray sandstone plots had a lower % fines compared to brown sandstone and mixed plots. The average pH for brown sandstone was 7.5, while gray sandstone averaged 7.6 and mixed were 6.8. Average tree volume (diameter^2 x height) was calculated for each species, and no significant differences were found among treatments. Overall survival rates for brown, gray and mixed sandstone were 100%, 80% and 87%, respectively.

Introduction

The forestry reclamation approach has become a preferred method in Appalachia for reclamation to forestry post-mining land uses. This approach requires the placement of 1.2 meters of uncompacted, weathered brown sandstone and pre-mining topsoil or best available substitute material. This substitute material is usually unweathered gray sandstone which is uncovered at great depths in order to reach the deepest seam of coal during coal extraction. Regardless of substrate type, an uncompacted substrate is more similar to surrounding native forest soils of Appalachia and has been shown to promote better tree growth compared to compacted reclaimed surface mine soils (Burger and Zipper, 2002). In this region, salvaging native topsoil and weathered brown sandstone near the pre-mining surface for replacement is often difficult and dangerous given the steep slopes. In addition, the small amounts of pre-mining topsoil sometimes do not warrant the expense and effort to save it. Unweathered gray sandstone or a mix of gray and brown sandstones may be acceptable alternatives for growth and development of forestry post-mining land uses. The problems with the use of gray sandstone as a topsoil material include alkaline conditions unsuitable for tree growth, higher soluble salts, and lower water availably due to its high rock fragment content. But research has shown that with time the pH and EC will decrease and soil fines will increase as the material rapidly weathers and takes on the characteristics favorable for hardwood growth observed in weathered brown sandstone and topsoil materials (Torbert and Burger, 2000). A mixture of both weathered and unweathered material may provide conditions for sustaining tree growth by incorporating the favorable characteristics of weathered material for tree establishment in the first years after reclamation. Then, later on, unweathered gray sandstone will weather to prolong those conditions as it begins to resemble the weathered brown material. A mixed sandstone substrate may also help to produce the quantity of material needed for reclamation without sacrificing substrate quality.

Aside from substrate type and compaction, selection of appropriate tree species and ground cover is essential for reforestation success (Torbert and Burger, 2000). Table 1 provides a list of appropriate species for forestry reclamation. A mix of the three types of tree species is desired to produce valuable hardwood timber, provide shelter and food for wildlife, and improve soil properties (Holl et al., 2001). Tree compatible ground cover includes a mix of non-competitive native grasses and legumes with a slow, low, sprawling habit (Table 2). These types of herbaceous species, when seeded at a low rate, will provide the appropriate ground cover to reduce erosion and will allow trees to establish (Holl et al., 2001). Fast growing tall grasses, popular in pasture reclamation, should be avoided as they compete for resources and attract wildlife that browse on and damage seedlings (Holl et al., 2001).

The objectives of this study were to examine the substrate physical and chemical properties over time of a mixture of weathered brown sandstone and unweathered gray sandstone compared to these substrates alone. We also evaluated tree species survival and growth across these three treatments.

Study Area

Consol Energy's Fola Coal Operation is located in Clay County, 35 miles east of Charleston, West Virginia. The operations consist of several underground and surface mines. Approximately 20,000 acres of contiguous land is potentially minable by surface methods. Surface mines extract coal from four seams, Upper Kittanning, Lower Kittanning (Five Block), Little Coalburg, Little Eagle, and Coalburg utilizing stripping shovels and front end loaders. The mine already has several mined areas reclaimed to Commercial Forestry or Forestry land uses and has several permits with those land uses as the designated land use option.

To demonstrate the effectiveness of brown vs. gray vs. a mixed sandstone substrate in growing commercially valuable hardwoods, eight 0.8-ha plots were established in winter of 2009. The locations of the plots were randomly selected for construction, and were composed of two plots of 1.2-m brown sandstone/top soil materials, two plots of 1.2-m gray sandstone material, and four plots of a mixture of gray and brown sandstone materials. In March 2009, after the materials had been in place for about three months, eleven species (Table 3) of trees were planted on 2.4-m (8-ft) centers resulting in a planting density of 1680 trees per ha (680 trees per ac). No ground cover was seeded. Native herbaceous species were allowed to volunteer from adjacent areas and from the seed bank in the materials.

Methods

Monitoring began in September 2009 when two randomly-selected 6.4-m radius tree sampling plots (405 m^2 or 1/10 ac) where established on each 0.8-ha substrate plot. Stem diameter at 1 cm above the soil surface and height to highest live growth of trees were measured and recorded for all trees within the 405-m^2 tree sampling plot. Approximately 10% of trees planted on each substrate plot were measured. Total tree survival was calculated based on the assumption that trees were planted at the correct spacing, which meant that 68 trees should have been located within each 405-m^2 plot (or 136 trees sampled per 0.8-ha plot).

Soil samples were collected from 0 – 15 cm and 15 – 30 cm at three locations within each tree sampling plot. Soil samples from the adjacent forest were also taken. All samples were air dried and then weighed. Samples were then passed through a 2 mm sieve, which separated the collected soil into two fractions: coarse (greater than 2mm) and fine (2mm and less). The coarse fraction was then weighted to determine the percentage fines in each sample.

The fine soil fraction was used in all soil chemical analysis. Soil pH was determined on a 1:1 mixture of 5g soil and 5ml deionized water. Samples were mixed on a reciprocating shaker for 15 minutes and then allowed to settle for an hour before pH was measured on a Beckman 43 pH meter and recorded. Soluble salts as measured by electrical conductivity (EC) was determined on a 1:2 mixture of 5g soil and 10ml deionized water, shaken on a reciprocating shaker, and then allowed to equilibrate for an hour or until suspended material settled. Electrical conductivity was measured using a Milwaukee C65 EC Meter and recorded. Extractable nutrients and cations were determined from a Mehlich 1 extract consisting of 0.05M HCl and 0.0125M H_2SO_4. The extract from all samples was analyzed with a Perkin Elmer Plasma 400 emission spectrometer for phosphorus, aluminum, iron, manganese, calcium, potassium, sodium, magnesium, copper, zinc, and nickel.

Results and Discussion

Based on the assumption of measuring a total of 136 planted trees per 0.8-ha plot, tree survival values for brown, gray, and mixed sandstone treatments were 100%, 80% and 87%, respectively (Table 4). Tree survival, after one growing season, was significantly higher on brown sandstone plots than gray sandstone plots. Mix sandstone was not significantly different from either brown or gray sandstone treatments. These survival rates in the gray treatment may be slightly lower than was actually experienced. The assumption of trees planted (based on 2.4-m spacing for a total of 1344 planted trees per 0.8-ha plot) was the best possible strategy to assess tree survival but in actuality fewer trees could have been planted in the gray sandstone plots. Here at Fola, the gray sandstone plots had large boulders and deeper and rocky gullies that would have presented difficulties in a consistent planting of trees on 2.4-m centers, potentially resulting in a lesser stocking rate when compared to brown and mix sandstone plots. Mix and brown sandstone plots typically had smaller rock fragments, more level areas and shallower and less rocky gullies. When trees were measured and counted, such an assumption was not intended to be made. Thus a better way to measure survival during subsequent years would be to count dead trees in addition to live trees.

Although average volume per tree was not significantly different among treatments, trees grown in brown sandstone appeared larger and healthier than trees grown in gray or mix sandstone. It should be noted that tree volume in this situation is potentially misleading. The average volume of trees is based on diameter and height, which varies amongst the eleven species planted. Species, however, are not evenly distributed among substrate plots and therefore are not sampled as such in the 405-m^2 tree sampling plots. The tree volume then becomes more an artifact of the natural size and growth of seedlings from the nursery where the stock was bought rather than the growth related to substrate properties. Plus the sampling plot may have been dominated by one species or another, which may have changed tree volume because of the predominant species found in the plot. Inherent species differences aside, after one summer trees are more than likely still living off nutrient reserves from the nursery media rather than relying on those in the soil solution.

All trees showed signs of wildlife damage which could have affected the tree survival and volume on all substrates. It is unknown if grazing had a significant effect on tree growth and survival when comparing treatments. Location of plots to adjacent wildlife habitats does pose an issue in analyzing tree survival and volume data. Some plots may be more prone to grazing due to closer proximity to existing undisturbed forest.

There were no significant differences between the two sampling depths in all treatments, including native soil samples (Table 4). Therefore, we chose to report only the values for the 0 – 15 cm sampling depth. There were no significant differences in percent fines between treatments but all sandstone treatments had significantly lower fines than the native soil (Table 4 and Figure 1).

Soil pH among sandstone treatments showed no significant difference, but again soil pH of native soil was significantly different at a value of 4.4. Soil pH for brown, gray and mixed sandstone was 7.5, 7.6, and 6.8, respectively. Brown sandstone, being more oxidized, usually demonstrates a lower pH than gray sandstone substrate, which is usually slightly more alkaline due to the higher carbonate content (Hearing et al., 2003; Emerson et al., 2009). The higher pH seen in the brown could be explained by its location within the geologic column. The material could have resided at deeper depths (10-20 m), reducing the amount of pyrite oxidation or being less exposed to leaching conditions where exchangeable bases are removed. In addition, less top soil would have been incorporated into the substrate which generally has a lower pH as demonstrated in the collected native soil samples. It is unclear why the pH of the mix treatment is lower than the other two. One explanation is simply that there was more variation in pH within the samples (Figure 2). The plots are composed of poorly mixed brown and gray sandstone. Spatial variability is an inherent property of all mine soils and pH values can dramatically change within a few meters of sampling locations (Hearing et al., 2003). Another explanation may be that the mixture had higher levels of native topsoil as part of the brown portion of the substrate.

Of the treatments, brown sandstone had the lowest electrical conductivity with a value of 84 μS cm^{-1}. This treatment was not significantly different from the native soil but was significantly lower than the other two treatments. Gray and mix treatments were not significantly different and were found to have electrical conductivity values nearly three times greater than brown and native soils (Table 4 and Figure 3). Gray and mixed treatments were similar to values found in mine soils studied by Emerson et al. (2009).

Extractable phosphorus was highest in the brown sandstone but phosphorus levels in all treatments were significantly higher than the native soil (Table 4). A similar trend was seen in these treatments in a study by Angel et al. (2008) when using a Mehlich III extraction. Although Emerson et al. (2009), using a Mehlich I extraction, found gray had higher amounts of extractable P than brown, a subsequent study showed that this P may not have been bio-available (Skousen and Emerson, 2010).

Extractable aluminum levels in all treatments showed no significant differences. However, all treatments had significantly lower aluminum levels than the amount extracted from native soil samples. This is expected as native soils are older and most exchangeable bases have been leached and replaced by aluminum ions (Table 4).

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Table 1. Eligible trees species for forestland post-mining land use on reclaimed surface mines in West Virginia (Burger and Zipper, 2002; WVDEP, 2000).

Crop Trees/Hardwoods
Black cherry *(Prunus serotina)*
Black oak *(Quercus velutina)*
Chestnut oak *(Quercus prinus)*
Northern red oak *(Quercus rubra)*
Pitch X loblolly pine *(Pinus rigida x taeda)*
Red maple *(Acer rubrum)*
Sugar maple *(Acer saccharum)*
Sycamore *(Platinus occidentalis)*
Virginia pine *(Pinus virginiana)*
White ash *(Fraxinus americana)*
White oak *(Quercus alba)*
Yellow poplar *(Liriodendron tulipifera)*
Nurse/Wildlife Trees
Black alder *(Alnus glutinosa)*
Black locust *(Robinia pseudoacacia)*
Blackhaw *(Viburnum prunifolium)*
Bristly locust *(Robinia hispida)*
Dogwood *(Cornus spp.)*
Eastern redbud *(Cercis canadensis)*
Hickories (*Carya spp.)*
Native Crabapple or hawthorn *(Rosacea spp.)*
White pine *(Pinus strobus)*

Table 2. Tree compatible groundcover species and seeding rates for forestland post-mining land use on reclaimed surface mines in West Virginia (WVDEP 2000).

Species	Seeding Rate
Grasses:	
Winter Rye *(Secale cereale)**	15 lbs/ac
Foxtail millet *(Setaria italica)***	5 lbs/ac
Weeping lovegrass *(Eragrostis curvula)*	2 lbs/ac
Redtop *(Agrostis gigantea)*	2 lbs/ac
Perennial rye grass *(Lolium perenne)*	2 lbs/ac
Orchardgrass *(Dactylis glomerata)*	5 lbs/ac
Legumes:	
Kobe lespedeza *(Lespedeza cuneata)*	5 lbs/ac
Birdsfoot trefoil *(Lotus corniculatus)*	5-10 lbs/ac
White or Ladino clover *(Trifulium repens)*	3 lbs/ac

*Used for fall seeding. **Used for summer seeding (June thru September).

Table 3. Species and rate of trees planted in 2009 on the eight substrate plots.

Species	Total # Planted	% of Total
Northern red oak *(Quercus rubra)*	1632	15
White oak *(Quercus alba)*	1958	18
Shagbark Hickory *(Carya ovata)*	217	2
Chestnut Oak *(Quercus prinus)*	1088	10
White Ash *(Fraxinus americana)*	1088	10
Yellow Poplar *(Liriodendron tulipifera)*	544	5
Sugar Maple *(Acer saccharum)*	1632	15
Black Cherry *(Prunus serotina)*	1088	10
Black locust *(Robinia pseudoacacia)*	327	3
Silky dogwood *(Cornus amomum)*	327	3
Eastern redbud *(Cercis canadensis)*	327	3
White pine *(Pinus strobus)*	652	6
Total	10,880	100

Table 4: Mean values for tree survival and volume, percent fines, soil pH, electrical conductivity, extractable phosphorus and extractable cations. Treatments not followed by the same letter for each parameter in columns are significantly different at $p<0.05$ level

	Trees						Extractable Cations						
Treatment	Survival	Volume	Fines	pH	EC	P	Al	Fe	Mn	Mg	Ca	K	Na
	%	$cm^3\ tree^{-1}$	%		$\mu S\ cm^{-1}$	- - - - - - - - $mg\ kg^{-1}$ - - - - - - -				- - - - - - - - - $cmol_c\ kg^{-1}$ - - - - - - - - -			
Brown	100 ^{a}	461 ^{a}	30 ^{b}	7.5 ^{a}	84 ^{b}	9.4 ^{a}	16 ^{b}	7.3 ^{c}	5.1 ^{b}	0.2 ^{b}	1 ^{a}	0.018 ^{a}	0.009 ^{a}
Gray	80 ^{b}	479 ^{a}	25 ^{b}	7.6 ^{a}	245 ^{a}	5.5 ^{b}	9.2 ^{b}	46 ^{a}	9.8 ^{a}	0.2 ^{a,b}	1 ^{a}	0.016 ^{a}	0.005 ^{b}
Mix	87 ^{a,b}	337 ^{a}	34 ^{b}	6.8 ^{b}	275 ^{a}	4.8 ^{b}	15 ^{b}	21 ^{b}	8.5 ^{a}	0.3 ^{a}	0.8 ^{a}	0.024 ^{a}	0.008 ^{a,b}
Native	---	---	77 ^{a}	4.4 ^{c}	74 ^{b}	0.5 ^{c}	157 ^{a}	27 ^{b}	5.9 ^{a,b}	0.1 ^{c}	0.1 ^{b}	0.023 ^{a}	0.004 ^{b}

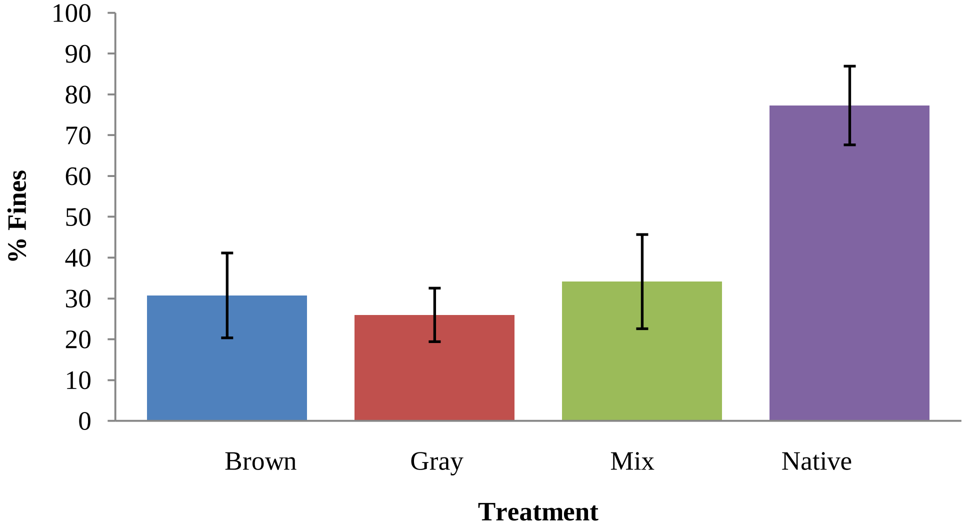

Figure 1. Average % Fines for each treatment with 1 standard deviation above and below mean represented by bar.

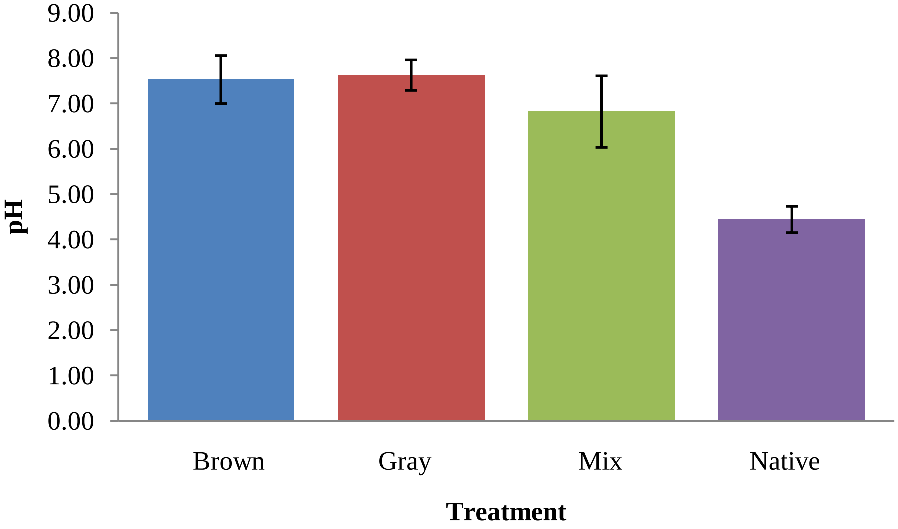

Figure 2. Average pH for each treatment with 1 standard deviation above and below mean represented by bar.

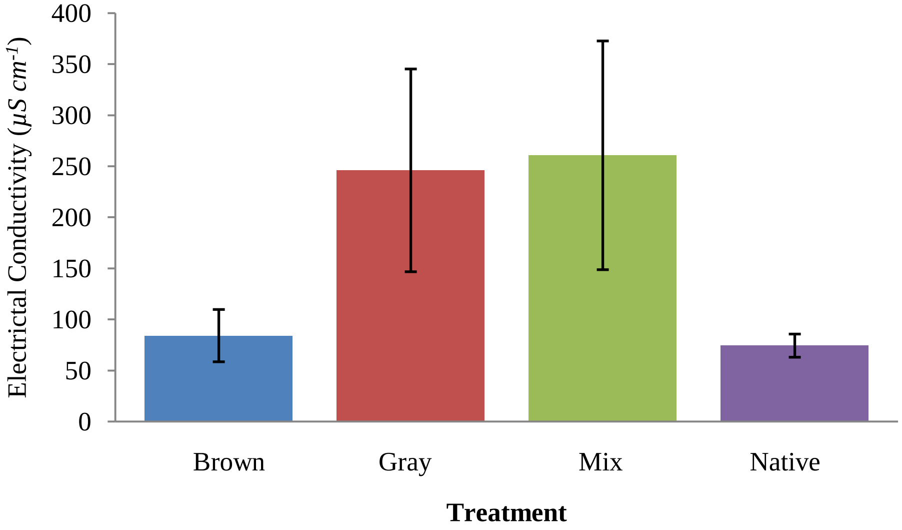

Figure 3. Average EC for each treatment with 1 standard deviation above and below mean represented by bar.