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Evaluation of tree growth and chemical, physical and biochemical soil properties of two reclaimed surface mines in West Virginia

Calene B. Thomas
West Virginia University

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**EVALUATION OF TREE GROWTH AND CHEMICAL, PHYSICAL AND
BIOCHEMICAL SOIL PROPERTIES OF TWO RECLAIMED SURFACE MINES IN
WEST VIRGINIA**

Calene B. Thomas

Thesis submitted to the College of Agriculture, Natural Resources and Design
at West Virginia University
in partial fulfillment for the requirements
for the degree of

Master of Science
In
Plant and Soil Sciences

Committee:

Jeffrey G. Skousen, Ph.D., Chair
Alan J. Sexstone, Ph.D.
Ray R. Hicks, Jr., Ph.D.

Division of Plant and Soil Sciences

West Virginia University
Morgantown, WV

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Keywords: Mine Land Reclamation, Forestry Reclamation Approach, Appalachian Regional Reforestation Initiative, compaction, sandstone overburden, bark mulch, soil biochemical properties.

ABSTRACT

Evaluation of Tree Growth and Chemical, Physical and Biochemical Soil Properties of Two Reclaimed Surface Mines in West Virginia

Calene B. Thomas

Advancements in technology and coal mining methods have accelerated the disturbance of valuable contiguous deciduous forests in the Appalachian region. In many instances, mountaintop mining has converted large expanses of forested mountaintops to rolling pasture and hay land that have been left abandoned to revert to shrub land dominated by invasive non-native species. Due to excessive soil compaction and heavy herbaceous cover, natural plant community succession from planted grasslands to hardwood forests is slow. Recently, efforts are being made to re-establish hardwood forests on mined land through careful spoil and amendment selection, and placement and planting of appropriate herbaceous and tree species. In order to evaluate tree growth and survival on selected spoils with various amendments, two study areas were established on two mountaintop mines in West Virginia. The oldest study area is Catenary Coal's Samples Mine in Kanawha County, WV, where three 2.8-hectare demonstration plots were established in 2005. Two plots were comprised of oxidized (brown) sandstone and one of un-oxidized (gray) sandstone. Half of all plots were "tracked" in to produce a smooth compacted surface. Care was taken to leave the other half of the plot relatively uncompact, producing a rough uneven surface. The study area was planted with a variety of hardwood tree species, mainly oaks, sugar maple and black cherry, on 2.4-m centers. Soil chemical properties and tree volume index and survival were evaluated for seven years. Substrate type had a significant effect on tree volume index with brown sandstone consistently outperforming gray sandstone. Of the eleven tree species planted, dogwood, black cherry, and red and white oak gave the highest growth index. Compaction did not have a significant effect on tree volume index. In 2011, pH, fines, Fe, P, and Zn were all significantly higher in gray sandstone. Differences were found for electrical conductivity and all extractable elements between 2005 and 2011. Aluminum was significantly lower in brown sandstone. Compaction had no effect on soil properties.

The second study area was a 3-ha demonstration plot created at Arch Coal's Birch River mine near Cowen, WV. The plot is comprised of two exclusive areas of brown and gray sandstone substrates. Approximately one third of each was amended with bark mulch and/or hydroseeded with fertilizer and low growing non-competitive herbaceous species, creating a total of eight treatments. The study area was planted with a variety of hardwood tree species, mainly oaks, sugar maple and black cherry, on 2.4-m centers. Soil chemical properties and tree survival and growth were evaluated for four years beginning in 2007. Using a model approach and Akaike's Information Criterion (AIC) to analyze tree and soil data, sandstone type and mulch had the highest empirical support for influencing tree volume index and soil chemical properties. No strong empirical support was found for any of our pre-selected models for predicting or inferring tree survival. Like the Catenary study, tree volume index on brown sandstone at Birch River was consistently higher than gray. After four years, hydroseeding had no effect on tree volume index, survival or soil chemical properties. Mulch application had the ability to improve tree growth in both sandstone types and had a strong influence on soil chemical properties.

In addition, soil organic carbon (SOC), microbial biomass carbon (MBC), total combustible nitrogen (TCN), potentially mineralizable nitrogen (PMN) was also measured for soil samples of the Birch River study area. Substrate had no effect on these properties. Hydroseed application had a significant effect on MBC and TMN. Both of these biochemical properties were higher in the hydroseed application treatment.

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1. Introduction

For over a century coal mining has been an important industry in West Virginia, creating jobs and generating revenue for the state and surrounding region. With advancements in technology and mining methods in recent decades, coal mining has accelerated the disturbance of the valuable contiguous forests in the Appalachian region (Townsend et al., 2009; Wickham et al., 2007). Mountaintop mining methods in many instances have converted large expanses of forested mountain tops to rolling pasture and hay lands. Touted for their economic potential, these pasture/hay lands have mostly remained unmanaged and have reverted to shrub land dominated by invasive non-native species (Torbert and Burger, 2000; Zipper et al., 2011). Due to excessive soil compaction and heavy herbaceous cover, natural plant community succession to hardwood forests is slow (Simmons et al, 2008). Invasive species, both shrubs and herbaceous plants, compete too fiercely for nutrients and available water (Burger et al., 2008; Skousen et al., 2006; Zipper et al., 2011). Combined with the harsh soil conditions, colonization and growth of trees is difficult.

In the last decade, the Office of Surface Mining (OSM) has encouraged coal operators and land owners to opt for forestry land uses in land reclamation and move away from pasture and hay land. Forested land could be an effective and beneficial land use producing valuable hardwood for timber and providing ecological services, such as increased water infiltration and watershed protection, wildlife habitat, and greater biodiversity (Byrd et al., 2002; Gorman et al., 2001; Larkin et al., 2008; Showalter et al., 2007; Zipper et al., 2011). Rapid tree regeneration and forest succession depends on soils with properties suited for forest reclamation. Therefore, reclamation specialists are interested in expediting this process of natural succession by

manipulating the placement and selection of sandstone substrate to maximize tree growth (Zipper et al., 2011).

The Appalachian Regional Reforestation Initiative has adopted a forestry reclamation approach (FRA) that includes five factors that contribute to healthy tree growth on reclaimed mine sites (Burger et al., 2005; Zipper et al., 2011). These include (1) substrate selection, (2) substrate placement, (3) tree selection, (4) herbaceous vegetation selection and application rate, and (5) tree planting technique. Mulches, while not recognized by the FRA, could impart beneficial characteristics to the growth matrix and improve tree growth.

With the success of the FRA, reclamationists and researchers are continuing to become interested in enhancing ecosystem services on these restored forests in the Appalachia coalfields. Physical and chemical properties of mine soils and their relationship to herbaceous and tree growth are becoming better understood and can help determine which spoil materials are to be placed on the surface for reclamation to a specific post-mining land use. Judging the potential of these spoil materials for plant growth is heavily dependent on soil properties that support plant community development, diversity, and sustainability of vegetation. Although bond release is contingent on the latter, a move towards restoration would include the evaluation of how well these substrates support other ecosystem components such as microbial populations and communities. Microorganisms play an essential role in nutrient cycling, soil formation, organic matter turnover, and ultimately plant establishment and long-term stability of a site. Physical, chemical and biological soil quality indicators are important in considering the long-term vegetation stability and plant community sustainability, and could provide a more comprehensive evaluation of reclamation success.

The objectives of the proposed study were to:

1. Evaluate tree survival and volume index on compacted and non-compacted substrate plots comprised of weathered brown sandstone and un-weathered gray sandstone at the Samples Mine in Kanawha County, West Virginia. Evaluate the same on weathered brown sandstone and un-weathered gray sandstone amended with bark mulch and hydroseed at the Birch River Mine in Webster County, West Virginia
2. Evaluate the soil chemical and physical properties of these mine soils.
3. Evaluate biochemical properties of weathered brown sandstone and un-weathered gray sandstone amended with hydroseed.

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2. Samples Mine

2.1. Literature Review and Objectives

The Appalachian Regional Reforestation Initiative has adopted a forestry reclamation approach (FRA) that includes five factors that contribute to healthy tree growth on reclaimed mine sites (Burger et al., 2005; Zipper et al., 2011). These include (1) substrate selection, (2) substrate placement, (3) tree selection, (4) herbaceous vegetation selection and application rate, and (5) tree planting technique. Mulch application, while not recognized as a step in the FRA, is an important component of revegetation practice to protect soil while vegetation is becoming established, and it is required by regulation. Mulch imparts beneficial characteristics to the soil growth material and can improve tree growth by conserving soil and modifying its properties.

Substrate selection has been shown to be a controlling factor in the success of post-mining land use. Studies by McFee et al. (1981), Torbert et al., (1990) and Casselman (2006) found that substrates derived from shale and siltstone reduced tree growth when compared to growth of trees in substrates derived from sandstone overburden. Two types of sandstone materials are often placed on the surface during reclamation in West Virginia. The differences in these substrates are mainly a result of their respective location in the geologic column. Oxidized sandstone, commonly called brown sandstone, is found closer to the surface and has been subjected to oxidizing conditions that typically produce materials with a pH ranging from 4.0 to 5.5 (Hearing et al., 2004). Un-oxidized sandstone, commonly referred to as gray sandstone, is generally more abundant and is located lower (below 10 m) in the geologic column (Grube et al., 1982). Consequently, these materials remain un-oxidized until moved to the surface. The pH of soils derived from this type of material is usually within the range of 7.5 to 8.0 (Hearing et al.,

2004). Torbert and Burger (2000) explained that the oxidized brown sandstone located close to the pre-mining surface possesses chemical and physical characteristics that benefit tree growth. In addition to a lower pH, these materials tend to have lower levels of soluble salts and higher percentages of fines (< 2mm) when compared to their un-oxidized gray sandstone counterparts. Studies by Daniels and Amos (1984), Torbert et al. (1988), Andrews et al. (1998), Rodrigue and Burger (2004), and Emerson et al. (2009) support this idea by citing low electrical conductivity, high percentages of fines and lower pH, amongst other properties, as being correlated to better tree growth.

Researchers conducting studies directly comparing these two types of sandstone-derived mine soils have reported higher growth in trees planted into oxidized types (Angel et al. 2008; Emerson et al., 2009; Showalter et al., 2010). This research has raised concerns about the ability of un-oxidized sandstone-derived mine soils to perform as a topsoil substitute. To make use of the abundance of this material, studies have examined tree growth in soils derived from mixtures (Angel et al., 2008) and mine soils amended with forest topsoil (Showalter et al., 2010). Both have reported growth to remain lower than growth in only oxidized sandstone-derived mine soils.

Compaction of surface materials is a required practice when regrading overburden materials to achieve post-mining land forms and to meet land stability safety regulations. After the final land contours are established and stabilized, operators then replace topsoil materials at suitable depths for the desired post-mining land use. When reclaiming surface mined lands to hay and pasture post-mining land uses, topsoil is replaced to depths of 15-50 cm depending on the amount salvaged prior to mining. As the last step of the process, bulldozers spread this material

and “track in” the soil leaving a uniform ground surface for seeding of aggressive forage species (Skousen and Zipper, 2010; Torbert and Burger, 2000). This process for reclaiming surface mined lands to pasture and hay land is well known and practiced, which results in complete coverage of the ground surface with quick establishing and persistent herbaceous species.

In forestry reclamation post-mining land uses, compaction of the ground surface in a similar manner as that done for pasture reclamation has been shown to prohibit good tree growth. Geyer (1972) found that tree growth in Kansas mine spoils was adversely affected by excessive compaction. Spoil banks with little or no grading had a higher survival rate in the first year and mortality in graded spoil banks increased over a 16-year period. Compaction was more closely correlated to survival and growth than substrate type. Heilman (1981) reported that Douglas fir (*Pseudotsuga menziesii* Mirb.) planted in soils with lower bulk density exhibited deeper and more extensive root systems than those planted on highly compacted soils. The better growth was attributed to the ability for root expansion and exploration for additional water and nutrients. In 1986, Daniels and Amos (1985) found that of 30 mine sites with weathered materials on the surface which had sparse or no vegetation, only one was found to be acidic. The other sites with poor vegetation were not due to other poor chemical properties, but the factor limiting plant growth at the other study sites was soil compaction. Therefore, compaction was the limiting factor for sites with favorable chemical properties where tree growth was shown to be poor. Compacted soils have less pore space with which to hold water and air needed for plant growth. Compacted soils prevent root expansion and water infiltration, both of which limit water availability during droughty conditions. Even small amounts of traffic on the surface increase compaction and lead to conditions that significantly reduce tree growth and survival (Angel et al., 2006). A number of studies with a variety of tree species have found that compaction reduces

tree survival and growth on disturbed land (Clayton et al., 1987, Lockaby et al., 1984; Torbert et al., 1988; Zeleznik and Skousen, 1996). Compaction was also cited as a hindrance to organic matter and N accumulation in Appalachian soils resulting in low microbial activity (Stroo and Jencks, 1982). Andrews et al. (1992 and 1998) found that rooting depth was the major limiting factor in tree growth, particularly white pine (*Pinus strobus* L.) on Virginia and West Virginia mine soils. Compacted layers found beneath the surface prevented root penetration.

To ameliorate the effects of compaction, researchers have found that ripping the surface layers of the site can help to reduce bulk density and increase tree growth. Like Heilman (1981), Philo et al. (1982) found that black walnut (*Juglans nigra* L.) seeded on ripped spoils established better in the first year and had a higher survival rate in the following year than those seeded on un-ripped spoils with similar characteristics. The effects of ripping have been explored by others (Ashby et al., 1997; Cleveland and Kjelgren, 1994; Skousen et al., 2009) and all have found similar results; tree survival and growth increases as bulk density decreases through ripping, but many have also mentioned that ripping still does not make the soil as good as material that was not originally compacted.

The objective of this study was to evaluate tree growth and survival on compacted and noncompacted weathered brown and unweathered gray sandstone substrates and to monitor potential effects of treatments on soil chemical characteristics.

2.2. Methods

2.2.1. Study Area

The Samples Mine, located 50 km southeast of Charleston, is owned by Arch-Magnum and operated by Catenary Coal Company. It spans three West Virginia Counties: Kanawha, Raleigh, and Boone. The mining process consisted of a truck/shovel operation and a dragline to excavate overburden from three Kittanning coal seams (7 Block, 6 Block, and 5 Block), and the Stockton, Coalburg, and Winifrede seams. The overburden includes sandstone with thin intermittent layers of shale. The pre-mining soils consisted mainly of a Clymer-Dekalb series (Typic Hapludults - Typic Dystrudepts) on moderate to severely steep slopes (Wolf, 1994).

In January 2005, three 2.8-hectare demonstration plots were constructed. Two were composed of 90% weathered brown sandstone and 10% pre-mining topsoil. One of these brown sandstone plots had material dumped to a depth of 1.5 m, while the other brown sandstone plot had material dumped at 1.2 m in depth. A third plot comprised of entirely gray unweathered sandstone was placed on the surface to a depth of 1.5 m. The plots were constructed by end-dumping material in adjacent conjoining piles. One half of each plot was graded with one or two passes of a dozer to avoid compaction, which produced a roughly graded surface. The other half of each plot was “tracked in” several times, as is usually done in reclamation to pasture land, producing a highly compacted surface. Six treatments were produced (Table 2-1). The layout of the study area can be seen in Figure 2-1.

Table 2-1. Soil treatment combinations at Catenary Coal’s Samples mine operation in Kanawha County, West Virginia.

Treatment	Abbreviation
1.2-m weathered brown sandstone compacted	4BC
1.2-m weathered brown sandstone noncompacted	4BNC
1.5-m weathered brown sandstone compacted	5BC
1.5-m weathered brown sandstone noncompacted	5BNC
1.5-m unweathered gray sandstone compacted	5GC
1.5-m unweathered gray sandstone noncompacted	5GNC

Figure 2-1. Treatment layout at Catenary Coal's Samples mine operation in Kanawha County, West Virginia. Not to scale.

In March 2005, the demonstration plots were planted with 15,510 trees on 1.8-m centers resulting in a planting density of 1,846 stems per ha. Eleven species of trees were planted (Table 2-2). However, some species were planted in greater numbers and due to planting strategy, species were not evenly distributed across the sites. In fall 2007, the plots were hydroseeded with a tree compatible ground cover at a seeding rate of 15.4 kg/ha (Table 2-3).

Table 2-2. Species and number of trees planted at Catenary Coal's Samples mine operation in Kanawha County, West Virginia.

Species	Number Planted	% of Total Planted
Black cherry (<i>Prunus serotina</i> Ehrh.)	465	3
Black locust (<i>Robinia pseudoacacia</i> L.)	465	3
Chestnut oak (<i>Quercus prinus</i> L.)	1,250	8
Eastern redbud (<i>Cercis canadensis</i> L.)	465	3
Gray dogwood (<i>Cornus racemosa</i> Lam.)	465	3
Northern red oak (<i>Quercus rubra</i> L.)	3,400	22
Sugar maple (<i>Acer saccharum</i> Marsh.)	1,500	10
Tulip poplar (<i>Liriodendron tulipifera</i> L.)	1,250	8
White ash (<i>Fraxinus americana</i> L.)	2,500	16
White oak (<i>Quercus alba</i> L.)	2,500	16
White pine (<i>Pinus strobus</i> L.)	1,250	8
Total	15,510	100

Table 2-3. Species and rate of ground cover hydroseeded at Catenary Coal's Samples mine operation in Kanawha County, West Virginia.

Species	Rate
	kg ha ⁻¹
Birdsfoot trefoil (<i>Lotus corniculatus</i> L.)	11.0
Perennial ryegrass (<i>Lolium perenne</i> L.)	2.2
Redtop (<i>Agrostis gigantea</i> L.)	2.2
Total	15.4

2.2.2. Trees

On demonstration plots, transects for monitoring tree survival and growth were arranged in an X pattern. Each transect began at the corner of a demonstration plot and extended 195 m toward the adjacent corner forming an X across the plot. Each transect was 2.7 m wide. The sampling technique for trees utilized two transects in each treatment combination and a total of four transects on each 2.8-ha demonstration plot. Height to highest live growth and stem

diameter 2.5 cm above the soil surface were recorded for every tree within all transects. Data collections occurred during the first weeks of August, every year from 2005 to 2011. Volume index was used as a proxy for tree growth. Volume index of tree biomass was calculated with the following equation (Angel et al, 2008; Emerson et al., 2009; Tschaplinski et al., 1998):

$$\text{Tree volume index (cm}^3\text{)} = \text{Height (cm)} \times \text{Diameter}^2 \text{ (cm}^2\text{)}$$

Tree survival was calculated by the difference between the number of trees sampled the first year, 2005 (by Emerson et al., 2009), and the last year, 2011.

2.2.3. Soil

In mid-summer from 2005 to 2011, soil samples from the top 15 cm were collected at five random locations within the two transects for every treatment combination. Samples were air dried, weighed and passed through a No. 10 sieve. All material less than 2mm was weighed and recorded as the fine fraction. The fine fraction was used for chemical analysis (2005 data from Emerson et al., 2009).

Extractable elements were determined using a Mehlich 1 extraction solution. Five grams from the fine fraction of each sample were placed in 45-mL polypropylene centrifuge tubes with 25 mL of Mehlich 1 extracting solution (0.05M HCl and 0.025M H₂SO₄). Supernatant was analyzed for phosphorus, potassium, calcium, magnesium, aluminum, iron, manganese, and zinc using a Perkin Elmer Plasma 400 emission spectrometer.

Soil pH was measured in a 1:2 mixture of 5 grams of soil and 10 mL of deionized water. Soluble salts, as determined by electrical conductivity, were measured on a 1:1 mixture consisting of 5 grams soil and 5 mL deionized water.

2.2.4. Ground Cover

Vegetation cover on demonstration plots was measured using 1-m² quadrats in twenty random locations within the two 2.7-m-wide transect boundaries for each treatment combination. Herbaceous cover, tree cover, standing water, and bare soil/rock were estimated and recorded as a percentage.

2.2.5. Data Analysis

Tree growth data were analyzed by one-way ANOVA by substrate, compaction, depth (for brown sandstone plots only), treatment combinations, and species. Tukey's multiple comparison test was used to determine significant differences between group means at $P < 0.05$. Growth of species with three or more individuals in each treatment combination was analyzed by one-way ANOVA by treatment combinations for 2011 data. Tukey's multiple comparison test was used to determine significant differences between group means at $P < 0.05$.

Soil data were analyzed by one-way ANOVA by treatment combinations within year for pH, percent fines, percent fines, EC, and extractable elements. Tukey's multiple comparison test was used to determine significant differences at $P < 0.05$. Soil data were also analyzed by t-test among years within treatment combinations.

Ground cover data were analyzed by one-way ANOVA to compare cover types (herbaceous, tree, bare soil or rock, water, and total cover) by soil treatment combinations for 2011. Tukey's multiple comparison test was used to determine significant differences at $P < 0.05$. We used the R language and Environment for Statistical Computing for all the above analyses (R Development Core Team, 2011).

2.3. Results

2.3.1. Trees

The effect of substrate type on tree growth was found to be significant at $P < 0.5$ (Table 2-4). Weathered brown sandstone showed significantly higher tree growth than unweathered gray sandstone with volume indices of 3504 cm^3 versus 266 cm^3 , respectively. Trees grown in weathered brown sandstone not only had a higher mean, they exhibited a wider range of values than trees grown in unweathered gray sandstone (Figure 2-2). Compaction treatment was not a significant factor in tree survival and volume growth index. Therefore, significant differences in treatment combination were only related to substrate type. Depth treatment in brown sandstone plots were significant at a $P < 0.1$. Tree volume index was greater in the 1.5-m deep plot with a mean index of 4273 cm^3 . Mean volume index on the 1.2-m deep plot was nearly half (Table 2-4). Species was a significant factor at $P < 0.1$.

Table 2-4. Main treatment effects for volume index and survival after seven growing seasons in four soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

		Volume Index	Survival
		cm ³	%
Topsoil	Brown Sandstone	3504 ^{a‡}	88
	Gray Sandstone	266 ^b	69
	Compacted	1427	81
	Non-compacted	1439	81
	1.2 m depth	2735 ^b	87
	1.5 m depth	4273 ^a	88
Treatment Combinations			
	4BC [†]	1632 ^a	87
	4BNC	3685 ^a	87
	5BC	6689 ^a	83
	5BNC	2279 ^a	93
	5GC	271 ^b	71
	5GNC	262 ^b	67
Species			
	Black Cherry	1004 ^{bc}	33
	Black Locust	7924 ^a	100
	Dogwood	1832 ^b	63
	Redbud	812 ^{bc}	50
	Red Oak	1434 ^b	73
	Sugar Maple	156 ^c	40
	Tulip Poplar	893 ^{bc}	63
	White Ash	731 ^{bc}	83
	White Oak	1554 ^b	82
	White Pine	650 ^{bc}	77

[†] See Table 2-1 for treatment descriptions.

[‡] means for each treatment within column group with the same letter are not significantly different at $P < 0.05$.

Figure 2-2. Boxplot of tree volume index of all tree species for four soil treatments at Catenary Coal’s Samples mine in Kanawha County, WV.

Black locust had the highest average volume index across all plots at a mean index of 7924 cm^3 , which result is commonly found on reclaimed areas. It is the first to colonize reclaimed sites and if planted it grows rapidly and expands where space is available. Black locust is a legume and fixes nitrogen thereby allowing it to proliferate on infertile mine soils. Dogwood had the next highest mean volume index of all species in the study with a mean volume index of 1833 cm^3 . However there were no individuals of this species found in the GNC treatment combination (Table 2-5), which if there were would have undoubtedly reduced the mean growth index. Sugar maple had the lowest mean volume (156 cm^3) among species. There were no significant differences for mean sugar maple volume index among treatment combinations (Table 2-6). However, Figure 2-3 illustrates the range of values for sugar maple volume index

and suggests that this species is capable of achieving high levels of growth in weathered brown sandstone compared to the limited range of volume index of trees grown in gray sandstone.

Table 2-5. Distribution of tree species in 2011 after seven growing seasons in four soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

Species	Treatment†						Total
	4BC	4BNC	5BC	5BNC	5GC	5GNC	
Black cherry	1	-	2	1	-	2	6
Black locust	27	36	11	36	1	5	116
Dogwood	1	4	1	4	7	-	17
Redbud	1	6	3	2	-	3	15
Red oak	12	16	14	14	14	20	90
Sugar maple	3	-	8	6	5	3	25
Tulip popular	5	1	7	8	6	7	34
White oak	16	25	14	17	4	11	87
White ash	18	9	19	8	14	11	79
White pine	3	4	6	4	6	4	27
Total	87	101	85	100	57	66	496

†see Table 2-1 for treatment descriptions

Only four of the species did not have three or more individuals in each treatment combination: Black cherry, Black locust, Dogwood, and Redbud (Table 2-5). Of the species represented by three or more individuals in each treatment, four showed significant differences with respect to mean volume index among treatment combinations: red oak, white ash, white oak, white pine (Table 2-6). All four showed a similar trend described earlier for sugar maple with respect to substrate type and value range (Figures 2-4, 2-5, 2-6, and 2-7). Tulip poplar exhibited a variable range across treatment combinations, with lower (but not significant) means for treatment combinations with gray sandstone (Figure 2-8).

Due to the relatively even distribution of red oak individuals (Table 2-5), we were able to evaluate red oak survival and volume index alone in a similar manner as for all tree species grouped together. Red oak behaved in a similar manner with brown plots having significantly

greater volume index, but with the exception that depth treatment in brown plots was not significantly different (Table 2-7).

Table 2-6. Mean tree volume index of tree species in 2011 after seven growing seasons in four soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

Species	Treatment†						Ave
	4BC	4BNC	5BC	5BNC	5GC	5GNC	
	----- cm ³ -----						
Black cherry	869	-	2158	523	-	161	1004 ^{bc}
Black locust	2437	6787	41184	4070	47	1901	7924 ^a
Dogwood	812	1537	793	4683	668	-	1832 ^b
Redbud	1040	1276	1025	178	-	22	812 ^{bc}
Red oak	1174 ^{b‡}	2962 ^a	3061 ^a	798 ^b	262 ^b	76 ^b	1434 ^b
Sugar maple	113	-	217	228	80	20	156 ^c
Tulip popular	646	527	1429	1445	351	423	893 ^{bc}
White oak	1453 ^{ab}	1507 ^{ab}	2104 ^a	1072 ^{ab}	5 ^b	140 ^b	731 ^{bc}
White ash	970 ^a	993 ^a	992 ^a	929 ^{ab}	296 ^{ab}	90 ^b	1554 ^b
White pine	2004 ^a	914 ^b	743 ^b	662 ^b	72 ^b	87 ^b	650 ^{bc}
Ave	1632 ^a	3685 ^a	6689 ^a	2279 ^a	271 ^b	262 ^b	

†see Table 2-1 for treatment descriptions

‡means for each treatment combination within rows with the same letter are not significantly different at $P < 0.05$. Significant differences were found only for species with 3 or more trees in every treatment combination.

Table 2-7. Main treatment effects for volume index and survival of Red oak after seven growing seasons in four soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

		Volume cm ³	Survival %
Topsoil	Brown Sandstone	2232 ^{a‡}	72
	Gray Sandstone	161 ^b	73
	Compacted	1427	64
	Non-compacted	1439	82
	1.2 m depth	2195	82
	1.5 m depth	2266	65
	Treatment Combinations		
	4BC†	1174 ^a	85
	4BNC	2961 ^a	80
	5BC	3061 ^a	56
	5BNC	1611 ^a	77
	5GC	261 ^b	60
	5GNC	76 ^c	86

† See Table 2-1 for treatment descriptions.

‡ means for each treatment within column group with the same letter are not significantly different at $P < 0.05$.

Figure 2-3. Boxplot of Sugar maple volume index for four soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

Figure 2-4. Boxplot of Red oak volume index for four soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

Figure 2-5. Boxplot of White ash volume index for four soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

Figure 2-6. Boxplot of White oak volume index in for four soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

Figure 2-7. Boxplot of White pine volume index in four soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

Figure 2-8. Boxplot of Tulip poplar volume index for four soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

2.3.2. Soil

It was found that depth treatment had no impact on soil properties. Therefore for ease of interpretation and discussion, 1.2-m and 1.5-m brown sandstone plots were combined and treated as one treatment. Therefore treatment combinations will be those found in Table 2-8.

Table 2-8. Soil treatment combinations at Catenary Coal's Samples mine operation in Kanawha County, West Virginia.

Treatment	Abbreviation
Weathered brown sandstone compacted	BC
Weathered brown sandstone noncompacted	BNC
Unweathered gray sandstone compacted	GC
Unweathered gray sandstone noncompacted	GNC

There were significant differences between 2005 and 2011 for pH, EC, and Fines (Table 2-9). Soil pH was significantly different among soil treatments with brown sandstone plots having a pH from 5 to 6, and gray sandstone plots being between 7 and 8. No changes were seen in soil pH within soil treatments between 2005 and 2011. Electrical conductivity of gray sandstone treatments decreased significantly from 2005 to 2011. Fines were significantly lower in gray compared to brown sandstone plots in 2005, and that finding was continued through 2011. All elements showed a significant change between 2005 and 2011 for most soil treatments.

Overall, pH, Fines, Al, Fe, P, and Zn were significantly different between soil types (Tables 2-9 and 2-10). No soil chemical properties were significantly affected by compaction treatment. Not all treatments were significantly different for pH, EC, and fines between 2005 and 2011. Treatment combination BC was significantly different between years with regard to pH

(although the change was not large). Electrical conductivity of gray sandstone treatments decreased significantly from 2005 to 2011 due to leaching of salts from particle surfaces. All

elements showed a significant change between 2005 and 2011 for most treatment combinations.

Table 2-9. Soil properties of samples from four soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.**

Properties	Treatments†			
	BC	BNC	GC	GNC
pH	----- su -----			
2005	*4.9 ^{b‡}	5.3 ^b	7.4 ^a	8.2 ^a
2011	5.7 ^b	5.5 ^b	7.9 ^a	7.9 ^a
Electrical conductivity	----- dS m ⁻¹ -----			
2005	0.55 ^a	0.38 ^{ab}	*0.17 ^{ab}	*0.22 ^b
2011	0.51	0.42	0.40	0.40
Fines	----- % -----			
2005	53 ^a	50 ^a	40 ^b	38 ^b
2011	50 ^a	53 ^a	38 ^b	36 ^b

† see Table 2-8 for treatment descriptions.

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

*denotes significantly different with that property between 2005 and 2011

**2005 soil data from Emerson et al. (2009).

Table 2-10. Soil properties of samples from four soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.**

Elements	Treatments†			
	BC	BNC	GC	GNC
	----- cmol _c kg ⁻¹ -----			
Mg				
2005	*9.9	*7.2	*7.8	*7.6
2011	4.7	3.9	6.0	5.1
K				
2005	*0.92	*0.92	*0.87	*0.83
2011	0.42 ^a	0.35 ^{ab}	0.26 ^b	0.25 ^b
Ca				
2005	13	*10	*16	*14
2011	13	4.5	8.0	9.5
Al	----- mg kg ⁻¹ -----			
2005	*580 ^{ab}	*610 ^a	*302 ^{ab}	*202 ^b
2011	315 ^{ab}	370 ^a	116 ^{bc}	104 ^c
Fe				
2005	*375	*615	617	*1054
2011	160 ^b	160 ^b	330 ^a	330 ^a
Mn				
2005	*495 ^a	*383 ^{ab}	257 ^{ab}	*115 ^b
2011	163	140	174	191
P				
2005	*720	*720	*677	*645
2011	60 ^b	60 ^b	190 ^a	184 ^a
Zn				
2005	*13 ^b	*15 ^{ab}	*22 ^{ab}	28 ^a
2011	9 ^b	6 ^b	15 ^a	17 ^a

† See table 2-8 for treatment descriptions.

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

*denotes significantly different within that element between 2005 and 2011.

**2005 soil data from Emerson et al. (2009).

Aluminum concentrations were significantly higher in weathered brown sandstone treatments (Table 2-10). Concentrations of Fe, P, and Zn were all significantly higher in gray sandstone treatments. Both pH and Al concentrations in gray showed a small range of values compared to brown sandstone treatment combinations. All extractable nutrients and Al concentrations were significantly lower in 2011.

Figure 2-9. Boxplot of soil pH in soil samples of four soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

Figure 2-10. Boxplot of % fines in soil samples of four soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

Figure 2-11. Boxplot of Al concentrations in soil samples of four soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

Figure 2-12. Boxplot of Fe concentrations in soil samples of four soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

Figure 2-13. Boxplot of P concentrations in soil samples of four soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

Figure 2-14. Boxplot of Zn concentrations in soil samples of four soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

2.3.3. Ground Cover

Vegetation and total ground cover in 2011 after seven growing seasons were significantly higher in brown sandstone treatments compared to gray sandstone, and were generally at least 30 times greater (Table 2-11). Compacted weathered brown sandstone treatments had a total average ground cover ranging from 67 to 96%, and non-compacted brown sandstone treatments had a slightly lower range of 56 to 58% (Table 2-11). Average ground cover for the unweathered gray sandstone treatment was always under 5%. Conversely, exposed soil and rock cover was significantly higher in unweathered gray sandstone treatments, generally being at least three times greater in unweathered gray sandstone treatments. Both the gray sandstone treatment combinations had very little vegetation cover averaging over 95% exposed soil and rock at the surface. Only one treatment combination, 1.2-m non-compacted brown sandstone, had standing water present in 2011.

Table 2-11. Mean ground cover on four soil treatments in 2011 at Catenary Coal's Samples mine in Kanawha County, WV.

Cover type	Treatments†					
	4BC	4BNC	5BC	5B-NC	5GC	5GNC
	----- % -----					
Herbaceous	63 ^{ab‡}	50 ^b	84 ^a	49 ^b	1 ^c	2 ^c
Tree	5	8	11	8	1	1
Total	67 ^b	58 ^b	96 ^a	56 ^b	2 ^c	3 ^c
Bare/Rock	32 ^b	27 ^b	5 ^c	38 ^b	98 ^a	97 ^a
Water	-	14	-	6	-	-

†see Table 2-1 for treatment descriptions

‡means for each cover within rows with the same letter are not significantly different at $P < 0.05$

Figure 2-15. Boxplot of total ground cover in 2011 on four soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

Figure 2-16. Boxplot of exposed soil and rock in 2011 on four soil treatments at Catenary Coal's Samples mine in Kanawha County, WV.

Ground cover of vegetation and exposed soil and rock in unweathered gray sandstone treatments exhibited a narrower range of values compared to weathered brown sandstone treatments (Figures 2-15 and 2-16). Non-compacted weathered brown sandstone treatment had the largest range of values for both cover types.

2.4. Discussion

2.4.1. Trees

Overall, tree growth in the weathered brown sandstone treatments outperformed those in unweathered gray sandstone treatments. Tree survival across treatments was very similar. Although trees in the unweathered gray sandstone treatments had poor growth, they appeared to be persisting. Compaction was not a significant factor influencing tree growth in this study.

These trends were consistent throughout the seven growing seasons (Table 2-12) (DeLong, 2010; Emerson et al., 2009). We believe compaction did not fall out as a significant factor because there was a large area of standing water in one transect in the brown uncompacted treatment combination. The trees in this transect were growing very poorly in the water logged substrate.

It is difficult to explain the significance of depth in the brown sandstone plots. We would have expected the 1.2-m plot to have a greater mean volume index because of the standing water found on the 1.5-m plot. The opposite of this was found. The number of individuals occupying each plot was very similar. Further investigation is needed to understand the reasons for these results.

Regarding volume index, previous studies have also reported similar findings. In a study on a surface mine in eastern Kentucky, Angel et al. (2008) found that weathered brown sandstone plots yielded significantly higher tree volumes than gray or gray and brown mixed plots after three years of growth. A greenhouse study by Showalter et al. (2010) reported higher root and shoot biomass for white ash, red oak, and tulip poplar grown in a weathered sandstone versus those grown in unweathered shale and unweathered sandstone. Based on these and other studies, weathered sandstone material has been highly recommended as a topsoil substitute for reforestation reclamation, so long as the material is not highly acidic or contains pyritic materials (Skousen et al., 2011).

Table 2-12. Mean tree volume index for 2005, 2007, 2009, and 2011 growing seasons in four soil treatments at Catenary Coal's Samples mine in Kanawha, WV.*

	Treatments†					
	4BC	4BNC	5BC	5BNC	5GC	5GNC
Volume	----- cm ³ -----					
2005	12 ^{a‡}	14 ^a	11 ^a	11 ^a	11 ^a	15 ^a
2007	85 ^{cd}	181 ^a	116 ^{bc}	159 ^{ab}	47 ^d	45 ^d
2009	638 ^b	928 ^a	414 ^{bc}	523 ^b	190 ^{cd}	105 ^d
2010	981 ^{ab}	1065 ^a	718 ^{ab}	649 ^b	216 ^c	126 ^c
2011	1632 ^a	3685 ^a	6689 ^a	2279 ^a	271 ^b	262 ^b

†see Table 2-1 for treatment descriptions

‡means for each cover within rows with the same letter are not significantly different at P < 0.05

* 2005-2009 data from Emerson et al. (2009) and DeLong (2010).

As noted previously, Black locust had the greatest volume index of all species due to characteristics which make it a good pioneer species. Pioneer species are known to volunteer and colonize disturbed sites quickly and invade into adjacent areas. They are frequently planted on disturbed sites because of their ability to assimilate water and nutrients in a variety of soil types and produce exceptional growth under harsh conditions (Huntley, 1990).

Average dogwood volume index was next highest in this study. This species is considered an early to mid-successional tree and helps modify the soil, creating conditions conducive to growth of late successional hardwoods (Burger et al., 2009). Dogwood leaf litter rapidly decomposes, allowing its mineral constituents to become rapidly available to other plants. For this reason it is considered a topsoil improver (Hepting, 1971). It exists and grows well on a variety of soils and tends to do best on well drained flat landscapes with soils ranging in pH from 6 to 7 (McLemore, 1990). Skousen et al. (2006) found that dogwood voluntarily colonized and grew well on surface mined lands. Many characteristics of the species make it well adapted to

mine soils and therefore explains why it grew well and better than other species in both sandstone types.

Sugar maple grew poorly in both sandstone types and had the lowest growth of all species planted on the site. Early growth rate of sugar maple is slow (Godman, 1990; Hicks, 1998). Sugar maples are capable of surviving long periods of growth suppression due to environmental factors and will regenerate under heavy shade (Godman, 1990). The species grows best in moist, well-drained loams (Godman, 1965) and this species in West Virginia commonly occurs in areas with high oak site indices (Trimble, 1973). These characteristics suggest that sugar maple may perform better in the future once surrounding trees have grown up around it, improving soil conditions and reducing the amount of direct sunlight resulting in a slightly cooler and moister environment.

Red oak performed better on weathered brown sandstone treatments as indicated by the significantly higher volume index. Its mean volume index overall was the highest of the two oaks at the site. The species is known to be one of the fastest growing native oaks in North America, tolerating a wide range of site characteristics (Hicks, 1998). It grows best on well-drained loam to silty clay loam soils in areas having a north and or north easterly aspects (Ivan, 1990). Its tolerance to a wide range of soil properties could be helpful in explaining why it has persisted in gray sandstone for seven growing seasons with populations comparable to those found in brown sandstone.

White ash attained higher volume index values in weathered brown sandstone treatments and also demonstrated a larger range of values. Skousen et al. (2009) cited white ash for their exceptional survival on surface mined land. In this study, white ash had the highest survival of

all species. Hawely (1918) describes the species as tolerant to a range of environmental factors and topographic situations. It is most frequently found growing in fertile, moist, moderately well-drained soils with high nitrogen, calcium and sulfur concentrations (Erdmann et al., 1979). It is a pioneer species that will readily volunteer in abandoned fields (Schlesinger, 1990). While capable of growing in low light conditions, white ash seedlings will grow rapidly when exposed to sufficient sunlight becoming nearly intolerant of shade with age (Schlesinger, 1990). Without competition from other trees, white ash will not develop into quality lumber and becomes branchy, but over time shaded branches will drop quickly (Wright, 1965).

White oak is a species considered sensitive to nutrient availability unless grown in sandy soil (Rogers, 1990). The species does well on a variety of sites except in very shallow dry soils (Minckler, 1965), which may explain why volume index for white oak in unweathered gray sandstone was significantly lower than for those individuals growing in weathered brown sandstone. The weathered brown sandstone treatments had some topsoil mixed in which improved soil water retention. While not investigated in this study, it is speculated that gray sandstone dried out more quickly. However, the limited number of plants sampled in the various treatment combinations could have limited the ability to detect significant effects.

Tulip poplar most frequently is found growing in deep, moist soils but is capable of growing well in a variety of soil conditions (Hough, 1936; Hicks, 1998). When growing in its preferred conditions, tulip poplar can out-compete most any of its competitors with the exception of white pine. But in poor conditions, tulip poplar is out-competed by trees more suited to the site conditions (Hicks, 1998). In this study, the species performed similarly in both weathered brown and unweathered gray sandstone.

2.4.2. Soil

No soil properties appeared to be significantly affected by compaction in this study. Sandstone type was the major factor responsible for almost all differences among treatment combinations. Soil chemical properties were predictable based on sandstone type. Researchers in the Appalachian region have documented the properties of a variety of mine soils forming from a wide range of mine overburdens. Soils forming in these plots were no exception and have qualities very similar to those documented in past research. A widely accepted generalization is the pH range of mine soils derived from weathered and unweathered sandstone materials. Weathered sandstone materials typically have a pH range of 4.5 to 6, with unweathered sandstones being from 6.5 to 8 (Roberts et al. 1988). Brown and gray treatments in this study had pH averages that fell within these ranges.

Aluminum concentrations were highest in brown sandstone treatments. Aluminum becomes available at pH less than 5 and less available with increasing pH (Havlin et al., 2005). Brown sandstone derived mine soils have lower pH falling within the range of higher Al availability. Also, weathered materials tend to have more Al and Fe oxides (Haering et al., 1993). Conversely, Fe concentrations were significantly higher in gray sandstone than brown sandstone treatments. The higher levels of Fe in the gray sandstone treatments could result in Fe-P complexes that would prevent future availability of P for plant uptake (Haering et al., 2004). Like Fe, P was significantly higher in gray sandstone treatments using Mehlich 1 extraction, but the phosphorus in gray sandstone was not necessarily plant available. Skousen and Emerson (2010) found that the higher extractable P levels in gray sandstone did not translate into higher available P levels based on leaching tests. In addition to Fe-P complexes at a pH above 7, P has

the tendency to bind to Ca thereby reducing its availability to plants in these soils with high Ca concentrations (Klock et al., 1984).

All macro and micro nutrient concentrations significantly decreased between 2005 and 2011. This was mostly likely a result of weathering. The sandstone derived mine soils have a low cation exchange capacity, potentially leading to future nutrient deficiencies.

2.5. Conclusion

In conclusion, after seven growing seasons weathered brown sandstone was found to be a more suitable tree growth medium and topsoil substitute in comparison to unweathered gray sandstone. Average tree volume index was consistently higher for trees grown in the brown sandstone treatments. After seven growing seasons, tree survival was similar among all treatments and tree species between brown and gray sandstone treatments. In this study, compaction was not a significant factor in tree growth. Brown sandstone treatments typically showed a wider range of values for most soil properties, while gray sandstone typically showed a more consistent pattern and more narrow range of values for the same properties. This suggests that brown sandstone weathers more unevenly or is inherently more variable than gray sandstone, resulting in a wider range of site characteristics suitable for a variety of tree species.

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3. Birch River Mine

3.1. Literature Review and Objectives

Competition from ground cover is a critical factor determining the outcome of forestry land use success. Past hydroseeding practices, implementing heavy rates of seeding with aggressive non-native Lespedeza (*Lespedeza cuneata* L.) and Kentucky-31 tall fescue (*Festuca arundinacea* L.) and heavy fertilization, were popular in early vegetation applications (Torbert and Burger, 2000). This combination of reclamation practices provided rapid, thick, and consistent ground cover. In a forestry reclamation setting, this type of ground cover grows too fast and competes too fiercely for nutrients, light, and water resources. When used in forestry, grain-producing forage crops further reduce tree survival by attracting rodents that will also feed on seedlings while girdling the stems (Burger et al., 2002; Skousen et al., 2009). It is necessary for some ground cover to be planted to stabilize soils. However this ground cover must have little effect on the establishment and growth of young tree seedlings. Tree-compatible ground covers are grasses and legumes that can provide soil stability through rapid germination but have a slow, sprawling growth habit so they do not over grow trees and prevent adequate lighting conditions (Torbert and Burger, 2000). In addition, ground cover species must tolerate mine soil characteristics and improve mine soil properties through such mechanisms as microbial growth, nitrogen fixation, and release and uptake of nutrients. These compatible species must be seeded at a low rate, 10 to 20 kg ha⁻¹, with less nitrogen fertilizer (Burger et al., 2005).

Conditions such as those mentioned above provide additional benefits by allowing native species to volunteer and germinate from native seed banks adjacent to plots and those found in salvaged original topsoil reapplied during reclamation (Burger et al., 2005; Holl et al., 2001; Showalter et al., 2010; Skousen et al., 2006). Decreased vegetation has been shown to result in

greater success of tree survival and growth (Burger et al., 2009; Chaney et al., 1995, King and Skousen, 2003, Rizza et al., 2007)

Bark mulch waste products from sawmill and timbering operations could have a place in mine reclamation. These wastes (bark, wood shavings, and sawdust) accumulate on log landings and are mixed with limestone gravel and soil. They typically end up in landfills. However, these materials could potentially help reclamation efforts (Falk, 1997). Disturbed soils often lack organic material, a soil component that aids in reduction of bulk density, increases water infiltration and increases soil stability through aggregation (Insam and Domsch, 1988). All of these result in the reduction of soil erosion and prevention of water loss and could help to promote healthy plant growth. Norland (2000) suggests that mulch benefits mine soil with respect to the above mentioned properties. Addition and subsequent decomposition of bark mulch may help to restore organic matter over time and ameliorate the negative impacts of disturbance on mine soils. Other types of organic mulches have been found to improve soil characteristics related to soil organic matter (Anderson et al., 2008; Wick et al., 2010). Studies by Ringe (1988 and 1989) determined that the added expense of applying bark mulch is more than offset by increased tree survival and growth.

In this study, we investigated the effects of mulching, hydroseeding, and sandstone type on hardwood tree growth. Our main objective was to evaluate tree growth as a result of all combinations of these factors. We have also examined soil properties related to these treatments.

The objectives of this study were to determine tree growth and survival on weathered brown and unweathered gray sandstone substrates, amended and not amended with herbaceous ground

cover and bark mulch treatments; and to evaluate soil physical and chemical properties as a result of these amendments.

3.2. Methods

3.2.1. Study Area

Arch Coal's (formerly International Coal Group) Birch River Operation is located near Cowen in Webster County, West Virginia, approximately 100 km northeast of Charleston. Approximately 1,620 ha of contiguous area are potentially minable by surface methods. Coal from the Upper and Middle Kittanning, Upper and Lower Clarion, Stockton and Coalburg seams are currently being mined. Overburden was moved from above the seams by shovels, front end loaders, bulldozers, trucks, and, until November 2009, by dragline. The vegetative cover on pre-mining land was a mixed hardwood forest. Gilpin and Gilpin-Dekalb series (Typic Hapludults) were the pre-existing soil types on the moderate to steep slopes of the region.

In November 2006, a 5-ha plot was created using two types of sandstone overburden. Half of the area was constructed with weathered brown sandstone, the other half with unweathered gray sandstone. Overburden materials were end-dumped into conjoining piles that were approximately 1.5-m deep throughout. To limit compaction, a bulldozer made only one pass over the piles to strike off the tops, resulting in approximately 1.2-m depth of rough graded material throughout the plot. In April 2007, a 15-cm deep layer of bark mulch was applied to a strip down the center of the plot which included portions of both sandstone types (Figure 3-1). Following mulch application, approximately 8,000 2-0 bare root seedlings were planted on 2.4m-centers by a professional planting crew. A list of tree species and their respective portions of the total are in Table 3-1. The following fall, ends of the plot were hydroseeded with a seed mix of compatible

herbaceous species (Table 3-2), and fertilized at a rate of 336 kg ha⁻¹ of 10-20-10 NPK. The treatments are found in Table 3-3.

Table 3-1. Species and number of trees planted at the Birch River Operation in Webster County, WV.

Species	Total Number Planted	% of Total Planted
Black cherry (<i>Prunus serotina</i> Ehrh.)	850	11
Northern red oak (<i>Quercus rubra</i> L.)	850	11
Sugar maple (<i>Acer saccharum</i> Marsh.)	850	11
White ash (<i>Fraxinus americana</i> L.)	850	11
White oak (<i>Quercus alba</i> L.)	850	11
Black locust (<i>Robinia pseudoacacia</i> L.)	800	10
Pitch X loblolly pine (<i>Pinus rigida</i> x <i>taeda</i>)	800	10
Tulip poplar (<i>Liriodendron tulipifera</i> L.)	600	8
Sycamore (<i>Platanus occidentalis</i> L.)	450	6
White pine (<i>Pinus strobus</i> L.)	400	5
Gray dogwood (<i>Cornus racemosa</i> Lam.)	350	4
Eastern redbud (<i>Cercis Canadensis</i> L.)	350	4
Total	8,000	100

Table 3-2. Species and rate of ground cover hydroseeded at the Birch River Operation in Webster County, WV.

Species	Rate
	kg ha ⁻¹
Birdsfoot trefoil (<i>Lotus corniculatus</i> L.)	11.2
Kobe lespedeza (<i>Kummerowia stipulacea</i> Maxim.)	5.6
Ladino clover (<i>Trifolium repens</i> L.)	3.4
Orchard grass (<i>Dactylis glomerata</i> L.)	5.6
Perennial ryegrass (<i>Lolium perenne</i> L.)	5.6
Redtop (<i>Agrostis gigantea</i> L.)	2.2
Weeping lovegrass (<i>Eragrostis curvula</i> Schra.)	2.2
Total	35.8

Table 3-3. Soil treatment combinations at the Birch River Operation in Webster County, WV.

Treatment	Abbreviation
weathered brown sandstone	B
weathered brown sandstone w/bark mulch	BM
weathered brown sandstone w/hydroseeding	BH
weathered brown sandstone w/bark mulch and w/hydroseeding	BMH
unweathered gray sandstone	G
unweathered gray sandstone w/bark mulch	GM
unweathered gray sandstone w/hydroseeding	GH
unweathered gray sandstone w/bark mulch and w/hydroseeding	GMH

Figure 3-1. Simplified diagram of treatment layout at the Birch River Operation in Webster County, WV. Not to scale.

3.2.2. Trees

To assess tree growth, we established eleven 3m-wide transects varying in length in order to span the width of the entire 5-ha plot. These same transects were used every year for tree and soil sampling since 2008. Height to highest live growth and stem diameter 1 cm above the soil surface was recorded for every tree within all transects. Data collections occurred during August of every year from 2008 to 2011. Volume index in cm^3 was used as an indicator of tree growth.

Volume index was calculated with the following equation (Emerson, et al., 2009; Angel et al., 2008; Tschaplinski et al., 1998):

$$\text{Tree volume index (cm}^3\text{)} = \text{Height (cm)} \times \text{Diameter}^2 \text{ (cm}^2\text{)}$$

Tree survival was calculated by finding the difference between the number of trees sampled the first year, 2008, and the last year, 2011.

3.2.3. Soil

The top 15 cm of soil from the surface was collected from four random locations within transects of each treatment combination in July of 2007 to 2010 (DeLong, 2010). In mulched areas, we sampled the mineral soil by scraping aside the bark mulch on the surface of the soil. In July 2011, the sampling regime was altered. Three samples were collected and composited from each experiment unit. An experimental unit is a treatment combination found in one transect. There are a total of 36 experimental units at this study site. These samples were used for chemical and physical analysis.

Soils were air dried and sieved through a 2 mm screen to separate the fine fraction (<2 mm) from the coarse or rock fraction (≥ 2 mm). The fine soil fraction was used for chemical analysis.

Extractable elements were determined using a Mehlich 1 extraction solution. Five grams from the fine fraction of each sample were placed in 45-mL polypropylene centrifuge tubes with 25 mL of Mehlich 1 extracting solution (0.05M HCl and 0.025M H₂SO₄). Supernatant was analyzed for phosphorus, calcium, magnesium, potassium, aluminum, iron, manganese, and zinc using a Perkin Elmer Plasma 400 emission spectrometer.

Soil pH was measured in a 1:2 mixture of 5 grams of soil and 10 mL of deionized water. Soluble salts, as determined by electrical conductivity, were measured on a 1:1 mixture consisting of 5 grams soil and 5 mL deionized water.

3.2.4. Data Analysis

We constructed five general linear models, representing working hypothesis of treatment factors to predict tree volume index. Each linear model contained one dependent variable (volume index) and one independent variable (a treatment or the interaction of two treatments). We used Akaike's Information Criterion (AIC) to compare the fit of each model to the data. AIC also allows candidate models to be ranked, something particularly useful for making management recommendations. The five linear models selected to predict volume index were (1) sandstone type only (SS), (2) mulch application only (M), (3) hydroseeding only (H), (4) an interaction of sandstone type and mulch application (SS*M), (5) an interaction of sandstone type and hydroseeding (SS*M), and (6) a model fitting all data to an intercept only, which is independent of treatment (I). This last model, I, represents the hypothesis that no treatment was useful in predicting tree volume index. Models that ranked lower than the last model, I, were not likely responsible for explaining trends or differences in the data. Delta AIC values that corrected for sample size bias (ΔAIC_c) were used to rank models and the model weight was used to evaluate the ability of the model to correctly predict volume index (Burnham and Anderson, 2002). No tree species was represented in all treatment combinations. Therefore, volume index was calculated for all trees in each treatment combination because volume data for individual tree species were unavailable for a comparison across treatments. Box plots were used to examine trends in the data.

The same working models were used to evaluate the influence of treatment on tree survival. We calculated survival by the difference of individuals occupying experimental units between 2008 and 2011. Trees volunteering on the site were not used in the analysis.

Finally, we performed PCA on standardized data to summarize the dominant trends. Data were transformed if needed to meet normality assumptions. One of the pair of redundant variables was excluded if correlation analyses showed an $r > 0.95$ ($r^2 > 0.90$). Principle components with eigenvalues >1.0 were considered significant and variables with factor loadings >0.6 were considered highly influential. We then created regression models to explain these factors from the experimental conditions on the site, and we evaluated their likelihood as above. The six general linear models for predicting selected soil chemical properties were (1) sandstone type only (SS), (2) mulch application only (M), (3) hydroseeding only (H), (4) an interaction of sandstone type and mulch application (SS*M), (5) an interaction of sandstone type and hydroseeding (SS*H), and (6) a model independent of treatment (I). We used the R language and Environment for Statistical Computing for all the above analyses (R Development Core Team, 2011).

3.3. Results

3.3.1. Trees

In 2008, model I (no treatment) ranked the highest of the model sets for predicting tree volume index (Table 3-4). With an AICc weight of 0.4, the I model had two times more empirical support to predict tree volume index than the next model. Models using hydroseeding (H), mulch application (M), and sandstone type (SS) alone to predict tree volume ranked below the I model with AICc weights of 0.19 to 0.14. The interaction models (SS*M and SS*H) ranked

at the bottom, both with AICc weights of 0.05. The ranking and weights of these models indicated that no treatment predicted tree volume the first year after tree planting. Treatments did not yet have a strong influence on growth and were unable to predict volume index, but they did have a slight influence according to the AICc weights of the treatment models.

One year later, the sandstone type and mulch application interaction model (SS*M) ranked the highest in the set of models, closely followed by the SS model with AICc weights of 0.48 and 0.36, respectively (Table 3-4). The sandstone type and hydroseeding interaction model (SS*H) ranked third with an AICc weight of 0.15, having less than half the empirical support of the second-ranked model (SS) and a third of the support for the SS*M model. Although the interaction model (SS*M) had the highest support in predicting tree volume index, mulch application alone was not able to do the same. Mulch (M) had no empirical support for predicting volume index and ranked below the I model, indicating it had less influence on tree growth in 2009. The same can be said for the H model.

In 2010, a similar trend was seen as in the previous year. The SS*M model ranked the highest, but the AICc weight more than doubled resulting in a value of 0.92 (Table 3-4). This top ranked model had 18 times more empirical support to predict tree volume index than the next ranked models, SS and M with AICc weights of 0.05 and 0.02, respectively. Sandstone and mulch were both important in predicting tree volume index but their interaction was more influential on volume index than either independent of the other. All other models had AICc weights of 0 indicating they were unable to predict tree volume index and therefore had little influence on tree growth in 2010.

The following year's AIC analysis yielded results similar to 2010. In 2011, the model ranking was the same, with the exception of models containing hydroseed application. Both of these models, H and SS*H, were ranked below the I model. AICc weight for the top ranked model, SS*M, was 0.72, followed by SS with a weight of 0.13 and M with a weight of 0.10. Again, the interaction of SS*M was much greater in predicting tree volumes than either sandstone and mulch alone. There was little empirical support for models containing the hydroseed treatment. AICc values and ranking for these models indicated they had little to no ability in predicting tree volume index and therefore most likely had little influence on tree growth in 2011.

Table 3-4. Model ranking using AIC for volume index of trees planted at the Birch River Operation in Webster County, WV.

Year	Model	K	AICc	Δ AICc	AICcWt	Cum.Wt	LL
2008	I	2	5452.75	0	0.40	0.4	-2724.36
	H	3	5454.23	1.48	0.19	0.59	-2724.09
	M	3	5454.37	1.62	0.18	0.77	-2722.16
	SS	3	5454.91	2.16	0.14	0.9	-2722.39
	SS*M	4	5456.96	4.2	0.05	0.95	-2722.39
	SS*H	4	5456.96	4.21	0.05	1	-2722.39
2009	SS*M	4	7206.19	0	0.48	0.48	-3599.05
	SS	3	7206.79	0.6	0.36	0.84	-3600.37
	SS*H	4	7208.55	2.36	0.15	0.99	-3600.23
	I	2	7215.35	9.16	0	0.99	-3605.66
	M	3	7215.43	9.24	0	1	-3604.69
	H	3	7216.84	10.64	0	1	-3605.39
2010	SS*M	4	8547	0	0.92	0.92	-4269.46
	SS	3	8552.66	5.66	0.05	0.98	-4273.3
	M	3	8554.56	7.57	0.02	1	-4273.24
	SS*H	4	8562.49	15.49	0	1	-4278.22
	I	2	8564.1	17.1	0	1	-4280.04
	H	3	8566.03	19.03	0	1	-4279.99
2011	SS*M	4	8422.6	0	0.72	0.72	-4206.24
	SS	3	8426.08	3.48	0.13	0.85	-4209
	M	3	8426.63	4.02	0.10	0.94	-4208.25
	I	2	8429.41	6.81	0.02	0.97	-4212.69
	SS*H	4	8429.63	7.03	0.02	0.99	-4211.79
	H	3	8431.26	8.65	0.01	1	-4212.6

Examining the boxplots of tree volume indices for sandstone and mulch treatment combinations illustrates the impact these treatments had on tree growth from 2009 to 2011 (Fig 3-2). In 2009, there was a considerable amount of overlap between interquartile ranges of treatment combinations. Gray sandstone amended with mulch appeared to have a wider range of tree volume index more comparable to brown sandstone without mulch than gray sandstone without mulch. The same trend was seen in 2010 and 2011. Tree volume indices in areas of gray sandstone without mulch did not reach the values of those in the other three treatment

combinations. The highest mean tree volume index, 1153 cm³, was found in brown sandstone mulch treatment combinations (Table 3-5). Areas of gray sandstone with mulch had a tree volume index of 729 cm³ which was comparable to all brown sandstone treatments. The lowest tree volume index for brown sandstone, 664 cm³, was found in brown hydroseeded areas. The lowest mean tree volume indices were found in treatments of gray sandstone without mulch amendment: 98 cm³ in gray sandstone alone and 64 cm³, in gray sandstone hydroseeded areas.

Figure 3-2. 2009-2011 box plots of tree volume indices for areas of brown (B) and gray (G) sandstone with (M) and without (NM) mulch application at the Birch River Operation in Webster County, WV.

Table 3-5. Mean volume index for eleven species of trees after four growing seasons in eight soil treatment combinations at the Birch River Operation in Webster County, WV*.

Year	Treatment†								Ave
	B	BH	BM	BMH	G	GH	GM	GMH	
Volume Index	----- cm ³ -----								
2008	43	50	36	27	27	17	48	14	40
2009	218	293	299	507	30	40	217	63	210
2010	582	712	1047	705	72	50	764	181	545
2011	821	664	1153	804	98	64	729	424	621
	----- % -----								
Survival 2011	78	85	85	60	84	79	96	100	84

† See table 3-1 for treatment descriptions.

*2008 and 2009 tree volume index data from DeLong (2010).

We found no strong empirical support for any of our pre-selected models for survival. Our results indicated no treatment strongly influenced tree survival. The independent model, I, ranked highest of the models at 0.31 (Table 3-6), but it was not much higher than other models (0.21 to 0.13). Mean survival ranged from 60 to 100% (Table 3-5).

Table 3-6. Model ranking using AIC for survival of trees planted at the Birch River Operation in Webster County, WV.

Model	K	AICc	ΔAICc	AICcWt	Cum.Wt	LL
I	2	323.99	0	0.31	0.31	-1824.41
SS	3	324.16	0.76	0.21	0.52	-1821.72
H	3	325.9	1.25	0.16	0.68	-1824.02
M	3	326.01	1.76	0.13	0.81	-1821.19
SS*M	4	326.29	1.96	0.12	0.93	-1824.38
SS*H	4	326.42	2.83	0.07	1	-1821.72

3.3.2. Soil

For this paper we focused on 2011 soil data but we will refer back to previous year's data when discussing general trends in the soil data.

No variables were correlated more than $r > 0.90$; therefore all measured properties were used in the PCA and AIC analysis. PCA revealed that Al, Fe, P, Zn and percent fines all loaded strongly in the negative direction, while Ca, pH and EC loaded strongly in the positive direction on principle component (PC) 1 (Table 3-7 and Figure 3-3). Mn and K loaded strongly on PC2 in the positive direction and Mg loaded strongly on PC2 in the negative direction.

Examination of the PC1:PC2 biplot for 2011 soil data (Figure 3-3) illustrated grouping of soils within treatments having similar properties. All points on the right side of the plot were soils from mulch treatment. Regardless of sandstone type, these soil samples on the right side of the plot tended to have higher pH, EC and higher concentrations of Ca (Tables 3-9 and 3-10). Soil properties of non-mulched treatments from both brown and gray sandstone areas were found on the left side of the plot. Brown sandstone and gray sandstone soil samples did not separate well from one another on the PC1:PC2 biplot. Interestingly, biplots from previous years showed that over time soils from the various treatments became less grouped (Figure 3-4). From 2009 to 2011, soil samples with mulch, regardless of sandstone type, always appeared to group on the side of the biplot where Ca, pH and EC loaded the strongest. In 2009 to 2010, samples without mulch appeared on the opposite side of the biplot where Al, Fe, P, Zn, and percent fines loaded the strongest. During these years, the soils also broke out into sandstone type.

Table 3-7. PCA results for first 3 PCs of 2011 soil properties sampled at the Birch River Operation in Webster County, WV.

Variables	PC1	PC2	PC3
Eigenvalue	5.88	2.77	1.44
% Variation	0.49	0.23	0.12
% Cumulative variation	0.49	0.72	0.84
Al	0.87	0.21	0.14
Fe	0.89	0.21	0.31
Mn	0.03	0.92	0.18
Mg	0.37	0.87	0.18
Ca	0.89	0.27	0.00
K	0.16	0.81	0.33
P	0.63	0.41	0.53
Zn	0.80	0.33	0.22
pH	0.69	0.19	0.62
EC	0.92	0.13	0.05
% Fines	0.60	0.03	0.55

Figure 3-3. PC1:PC2 biplot of 2011 soil properties sampled at the Birch River Operation in Webster County, WV.

Figure 3-4. PC1:PC2 biplots of 2008 to 2010 soil properties sampled at the Birch River Operation in Webster County, WV.

Interaction between sandstone type and mulch had the strongest influence on soil properties loading on PC1 (Table 3-8) with an AICc weight of 0.81. Mulch alone also had an influence on soil properties of PC1 (0.19) but not as strong as the interaction with sandstone. AICc weights for all other models were 0, indicating that hydroseed, hydroseed and sandstone interaction and sandstone type alone had little influence on soil properties loading strongly on PC1. Box plots of pH, EC and Ca concentration indicated that areas with mulch, regardless of sandstone type, had higher mean values than those areas without mulch (Figures 3-5 and 3-6). Brown sandstone exhibited lower pH values than gray sandstone or mulch treatments, with means ranging from 5.1 to 5.4 (Table 3-9). EC and Ca concentrations in mulched areas also had a larger range of values compared to non-mulched areas (Figures 3-5 and 3-6). Trends for percent fines were less clear, but according to the box plot in Figure 3-5, it appeared that brown sandstone without mulch had the highest mean percent fines at 47% (Table 3-9). Gray sandstone alone and treatments with mulch had lower percent fines ranging from 34% to 43%.

Table 3-8. Model ranking using AIC for PC soil analyses with treatments at the Birch River Operation in Webster County, WV.

PC	Model	K	AICc	Δ AICc	AICcWt	Cum.Wt	LL
PC1	SS*M	4	110.08	0	0.81	0.81	-50.4
	M	3	113.01	2.93	0.19	1	-53.13
	I	2	169.26	59.18	0	1	-82.45
	SS	3	170.01	59.93	0	1	-81.63
	H	3	171.64	61.55	0	1	-82.44
	SS*H	4	172.54	62.46	0	1	-81.63
PC2	I	2	142.31	0	0.45	0.45	-68.97
	SS	3	144.39	2.08	0.16	0.61	-68.82
	H	3	144.54	2.23	0.15	0.76	-68.89
	M	3	144.63	2.32	0.14	0.9	-68.94
	SS*H	4	146.77	4.46	0.05	0.95	-68.74
	SS*M	4	146.85	4.54	0.05	1	-68.78

Table 3-9. 2008-2011 soil properties in eight soil treatment combinations at the Birch River Operation in Webster County, WV.

Properties	Treatments†							
	B	BH	BM	BMH	G	GH	GM	GMH
pH	----- su -----							
2008	4.7	4.8	7.1	8.1	7.9	7.4	7.0	6.9
2009	4.8	5.4	7.5	7.8	7.8	7.8	7.5	7.0
2010	5.0	5.3	7.6	6.7	7.4	7.1	7.6	7.6
2011	5.1	5.4	7.7	7.7	7.5	7.3	7.7	7.7
Electrical conductivity	----- dS m ⁻¹ -----							
2008	0.12	0.06	0.28	0.39	0.12	0.12	0.28	0.40
2009	0.05	0.07	0.30	0.30	0.08	0.11	0.33	0.29
2010	0.08	0.08	0.42	0.35	0.09	0.16	0.53	0.49
2011	0.04	0.04	0.38	0.34	0.05	0.04	0.35	0.48
Fines	----- % -----							
2008	57	47	24	26	41	33	34	32
2009	52	49	37	41	40	36	42	35
2010	38	41	31	33	25	26	24	24
2011	47	47	34	37	37	43	38	36

† See table 3-1 for treatment descriptions

*2008 and 2009 soil data from DeLong (2010).

Figure 3-5. 2011 box plots of pH, EC, and percentage fines from samples taken from areas of brown (B) and gray (G) sandstone with mulch (M) and without mulch application at the Birch River Operation in Webster County, WV.

In general, Al, Fe, P, and Zn concentrations were elevated in treatments without mulch. Al and Zn were typically highest in brown sandstone treatments without mulch (Figure 3-6). Mean Al concentrations in brown sandstone treatments without mulch ranged from 268 to 417 mg kg⁻¹ (Table 3-10). Fe and P concentrations were highest in gray sandstone treatments without mulch. Mean Fe concentrations in gray sandstone treatments without mulch ranged from 184 to 255 mg kg⁻¹ (Table 3-10) and P concentrations ranged from 46 to 61 mg kg⁻¹ with the lowest soil P concentrations in brown and gray, mulched, hydroseeded plots.

Returning to AIC analysis, no treatment appeared to have an influence on soil properties loading strongly on PC2. The model fitting all data to an intercept regardless of treatment ranked the highest with an AICc weight nearly three times more than the weight of the next three ranking models: sandstone type, hydroseed, and mulch alone. Both interaction models ranked the lowest with an AICc weight of 0.05 (Table 3-8). These results were supported by both the mean values for Mg, Mn, and K found in Table 3-10 and the boxplots for the same elements in Figure 3-6. There was no distinct pattern among treatments for these elements. In addition they

appeared to have large overlapping ranges of values among treatments of brown and gray sandstone with and without mulch.

Table 3-10. 2008-2011 soil properties in eight soil treatment combinations at the Birch River Operation in Webster County, WV*.

Elements	Treatments†							
	B	BH	BM	BMH	G	GH	GM	GMH
Mg	-----cmol _c kg ⁻¹ -----							
2008	9.0	3.0	8.8	17	7.1	12	22	29
2009	4.2	4.7	15	15	5.7	5.7	14	11
2010	4.1	2.7	14	15	4.1	4.5	12	14
2011	4.4	4.6	10	7.7	4.2	4.4	8.6	6.3
K								
2008	0.78	0.88	1.1	1.7	0.86	1.1	1.2	1.7
2009	0.43	0.56	0.80	0.80	0.35	0.47	0.68	0.74
2010	0.07	0.06	0.89	0.82	0.30	0.41	0.76	0.87
2011	0.44	0.45	0.71	0.34	0.31	0.34	0.36	0.37
Ca								
2008	6.6	2.5	30	97	9.0	15	68	110
2009	4.2	0.63	113	109	9.2	10	124	91
2010	3.7	3.3	70	71	6.5	8.1	77	74
2011	4.5	5.0	120	71	5.4	4.1	77	77
Al	-----mg kg ⁻¹ -----							
2008	-	-	-	-	-	-	-	-
2009	182	850	238	145	84	83	206	727
2010	171	45	96	195	88	100	-	200
2011	268	417	156	31	73	89	89	5
Fe								
2008	384	497	314	37	1608	3270	1034	454
2009	89	258	81	142	375	359	65	185
2010	65	130	65	84	304	407	17	40
2011	116	177	70	12	184	255	20	8
Mn								
2008	912	303	899	1728	716	1229	2307	2980
2009	423	482	1547	1534	575	573	1457	1165
2010	493	326	1710	1799	495	545	1406	1730
2011	448	464	1102	578	428	447	870	640
P								
2008	22	15	32	6.7	96	101	38	10
2009	16	63	15	32	141	202	21	12
2010	15	31	10	12	69	80	11	10
2011	17	26	17	4.6	61	46	4.3	6.6
Zn								
2008	21	16	33	9.2	26	30	29	10

2009	23	24	13	15	21	23	17	12
2010	19	11	1.4	4.9	8.6	15	0.2	1.9
2011	24	23	7.9	3.4	11.63	18	4.0	0.6

† See table 3-1 for treatment descriptions

*2008 and 2009 soil data from DeLong (2010).

Figure 3-6. Box plots of extractable elements from samples taken in 2011 from areas of brown (B) and gray (G) sandstone with mulch (M) and without mulch application at the Birch River Operation in Webster County, WV.

3.4. Discussion

3.4.1. Trees

In this study, the interaction between sandstone type and mulch was the most influential treatments on tree growth in 2009 to 2011. Sandstone type and mulch alone had little prediction ability on tree volume index, but large disparities were evident between brown sandstone and gray sandstone without mulch. Gray sandstone without mulch continually under-performed all treatments (except for tree survival) and exhibited the poorest tree volume index. This trend is commonly seen in studies comparing the two mediums. Results from studies by Emerson et al. (2009) and Angel et al. (2008) found that trees in brown sandstone had greater volume index than trees in gray sandstone. Sandstone types amended with mulch exhibited a larger range of tree volume indices and generally a higher mean tree volume index. The sandstone types may become more important to tree growth as trees become more deeply rooted in the mineral soil. Although not investigated, it is speculated that the mulch was the primary rooting medium for these small trees and not the sandstone type beneath the mulch layer. As mulch decomposes and becomes more incorporated into the mineral soil, the current trend may continue. Differences between mulch and non-mulch areas could also be due to differences in micro climate. Bark mulches have the ability to retain water and heat, preventing extreme conditions that may occur in the bare mineral soil.

Differences in growth may be an artifact of uneven species distribution, rather than a product of treatment conditions. Eleven different tree species were planted across the site, each with different seedling sizes and early growth characteristics. Logistics of planting did not allow for random planting resulting in the same tree groupings of the same species and even species distribution over the entire plot. Species were not represented in all treatments or were over represented in others (Table 3-11). Due to differences in original seedling size and growth habits, it is possible that mean volume indices were inflated or underinflated based on species

distribution. Looking at individual species may have been more appropriate but this was not possible in this study because of some tree species not being represented in all treatments, the small sample sizes in each treatment, and lack of replication.

Table 3-11. Number and distribution of eleven species of trees after four growing seasons in eight soil treatment combinations at the Birch River Operation in Webster County, WV.

Species	Treatment†								Total
	B	BH	BM	BMH	G	GH	GM	GMH	
Black cherry	7	15	2	-	5	-	3	3	35
Black locust	17	88	13	8	8	10	13	6	163
Dogwood	-‡	-	-	-	2	-	1	-	3
Redbud	2	-	1	-	3	-	1	-	7
Northern red oak	8	17	1	-	7	3	5	2	43
Sugar maple	16	10	1	-	2	3	4	1	37
Sycamore	4	6	-	2	2	-	3	2	19
Tulip poplar	4	6	3	-	9	3	8	1	34
White ash	7	12	2	3	8	2	4	1	39
White oak	14	16	2	2	8	3	4	2	51
White Pine	12	10	6	1	8	2	5	2	46
Total	91	180	31	16	62	26	51	20	477

† See table 3-1 for treatment descriptions

‡ Indicates no individuals were present in treatment

The ranking and weight of models including hydroseed application indicated that a seeding rate of 32 kg ha⁻¹ did not constrain tree growth. No effect of fertilization or hydroseeding on tree growth was observed five years after reclamation.

Tree survival was not affected by treatments. While slightly lower survival rates were observed in non-amended gray sandstone as opposed to gray sandstone with amendments, there was no strong evidence that sandstone type influenced survival. Visual observations in the field indicated that the quality of trees in gray sandstone was lower than in brown sandstone, yet they were persisting. Emerson et al. (2009) and Angel et al. (2008) similarly found no significant

differences in survival between the two sandstone types. Trees in all treatments in our study showed signs of wildlife browsing and the impact of this was not addressed in our analyses.

3.4.1. Soil

The pH for five of the eight treatment combinations fluctuated over the four years but appeared to have slightly increased from 2008 to 2011 (Table 3-9). Brown sandstone with mulch and hydroseed, and both gray sandstone treatments without mulch have slightly lower values in 2011 compared to 2008, but again had shown fluctuation over four years. Decreasing pH was observed in similar reclaimed mine soils of southwest Virginia in a study by Haering et al. (2004). The pH values decreased over the first three years of the study then rebounded to near initial levels or remained the same for the duration of the study. The increase in pH was attributed to the exposure and subsequent weathering of carbonates. Emerson et al. (2009) also reported fluctuations of pH values over a three year study. The overall pH values of the two non-mulched sandstone types were similar to those found in the same study by Emerson et al. (2009) with values for brown sandstone ranging from 4.5 to 6.1 and from 8.1 to 8.2 for gray sandstone. Showalter et al. (2010) reported a pH of 5.53 for brown sandstone and 8.38 for gray sandstone. Gray sandstone values were slightly higher in these studies but comparable to those found in this study. The elevated pH of all mulch treatments regardless of sandstone type can be attributed to the presence of limestone gravel in the bark mulch. Limestone was added as aggregate on log landings and incorporated into the mulch during machinery operation at the sawmill.

The presence of limestone in the mulch also accounted for the elevated EC in mineral soil below the mulch. EC values for mulch treatments were nine to 12 times higher than non-mulch treatments. All values were still less than 0.5 dS m^{-1} and were not high enough to negatively

impact tree growth. According to McFee et al. (1981), EC values of 1.0 dS m^{-1} and greater are potentially detrimental to tree growth on reclaimed mine lands. No differences in EC for sandstone type were observed.

The elevated levels of Ca and Mg in mulched areas were also caused by limestone in the bark. After four years, little difference was observed in Ca concentrations among non-mulched sandstone treatments. In previous years, gray sandstone exhibited slightly elevated levels, and an overall decrease in Ca concentration has occurred in both sandstones. In other studies, elevated levels of Ca in gray sandstone were reported and were likely a result of carbonate weathering (Haering et al., 2004)

Concentrations of Al, Fe, P, and Zn over time and within treatment combinations fluctuated and did not show clear trends. Overall, concentrations of these elements were lower on mulched areas. The reduction of Al, Fe, P and Zn in mulched areas could be the result of metal complexes with organic matter. Both P and Zn have a high affinity for organic matter in soils (Havlin et al., 2005). Higher levels of Al observed in brown sandstone was expected since weathered materials tend to have more Al and Fe oxides (Haering et al., 1993). On the contrary, the gray sandstone had higher concentrations of Fe than the brown and has shown this trend since the beginning of the study. The higher levels of Fe in the non-mulched areas could result in Fe-P complexes that would prevent future availability of P for plant uptake (Haering et al., 2004). Concentrations of P in gray sandstone remained higher than those found in brown sandstone over the four years of the study. However, concentrations of P in gray sandstone appeared to decrease more rapidly over time. Phosphorus found in gray sandstone was not necessarily plant available (Skousen and

Emerson, 2010). In addition to Fe-P complexes at a pH above 7, P has the tendency to bind to Ca reducing the availability to plants (Klock et al., 1984).

Five years after reclamation, any effects of hydroseeding, including fertilizer added with the seed, on soil chemical properties have been erased with time and by natural processes.

3.5. Conclusions

In this study, sandstone type and application of bark mulch had large effects on tree volume index. Survival was not influenced by any sandstone type, mulch or hydroseeding treatment. Four years after reclamation, hydroseeding at a rate of 32 kg ha⁻¹ had no effect on tree volume index or soil properties. Interaction between sandstone type and mulch was most influential on tree volume index and soil chemical properties. Sandstone type and mulch strongly influenced soil chemical properties. Mulch application was capable of altering the inherent chemical properties of sandstone overburden materials and could potentially create more suitable medium for tree growth.

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4. Soil Biochemical Properties Investigation

4.1. Literature Review and Objectives

A diverse microbial population and activity in soils are essential for sustained primary productivity in ecosystems given that they are responsible for the majority of decomposition, and subsequently, nutrient cycling in all terrestrial ecosystems. Yet, microbial populations, activities and health are dependent on vegetation composition and status. Heterotrophic bacteria require organic compounds to carry out metabolic functions. These compounds are mainly introduced to the soil environment in the form of plant litter. In addition, edaphic factors heavily influence the status of both microbial and plant communities. These include temperature, water availability, texture, pH, cation exchange capacity, nutrient levels, and toxic elements (Visser, 1985). Nutrient cycling is of extreme importance in soil fertility. Microorganisms participate in and facilitate nutrient cycling through immobilization and mineralization of organic compounds that have been introduced into the system.

Any drastic land disturbance dramatically alters and disrupts the integrity of the existing plant community, soil resource, and microbial components of an ecosystem. In order to restart and maintain any long or short-term ecosystem function and stability on disturbed areas, all contributing components must be accounted for, measured before disturbance, and then re-established as quickly as possible during reclamation. The importance of microbial processes on ecosystem stability has generated significant interest in understanding the microbial dynamics in reclaimed mine lands and their link to improving soil quality (Anderson et al., 2008; Chodak et al., 2009; Machulla et al. 2005; Stephens et al., 2001). In addition, researchers are interested in developing methods that can accurately measure microbial activity, community composition and

function which helps to evaluate reclamation success and the return and re-establishment of ecosystem services (Haney et al., 2008; Ingram et al. 2005; Zipper et al. 2011).

Without reclamation, soil microbial communities are slow to establish (Chodak, 2009) and even with reclamation, microbial activity may take several decades to reach stable conditions found in native soils (Insam and Domsch, 1988; Stephens et al., 2001). Several decades are usually required before a variety of organic matter sources are added and stable compounds are synthesized in mine soils to achieve a high number and diversity of microorganisms. Although some amended mine soils have shown an increase in biological activity through the incorporation of a carbon source (Elkins et al., 1984; Lindermann et al., 1984), Bendfeldt (2001) reported that after 16 years organic amendments yielded no significant difference in Appalachia mine soils with regards to aggregate stability, mineralized N, and soil organic matter (SOM) content. The one difference noted was mine soils amended with municipal sewage sludge had twice the amount of extractable P after 16 years. This could be potentially important since P, in some situations, becomes the limiting factor in plant growth in these newly created mine soils (Daniels and Zipper, 1988). Other studies (Stephens et al., 2001; Stroo and Jencks, 1982) have reported initial increases in microbial activity following reclamation with the addition of fertilizers and lime and rapid herbaceous plant growth. This increase in activity is seen for the first few years after reclamation but easily decomposable organic matter is rapidly consumed resulting in an overall decline of microbial activity with time if no further introductions of external nutrients and organic matter sources are applied.

A recent greenhouse study by Showalter et al. (2010) compared tree growth in forest topsoil alone to mixtures of topsoil amended with weathered sandstone, unweathered sandstone, and

unweathered shale, as well as these sandstones and shales alone as growth media. Soil chemical and microbial properties were measured for all treatments and correlations among these properties and growth of ash (*Fraxinus americana* L.), red oak (*Quercus rubra* L.), and tulip poplar (*Liriodendron tulipifera* L.) were explored. It was found that weathered sandstone's (amended with topsoil and not) pH, microbial activity, and water availability were more similar to forest topsoil than any other treatment. In addition, growth of ash and red oak was greater in the amended and unamended brown sandstone mine soil. Overall, topsoil-amended mine soil materials showed greater tree growth and higher microbial activity. The mine soil treatments with topsoil not only aided in restoring soil microorganisms but increased native herbaceous cover by providing a viable seed bank. Coal operators stockpile topsoil until its use in reclamation. Microbial biomass and activity have been shown to decrease with depth and over time in stockpiled topsoil (Visser et al., 1984; Harris et al., 1987). The use of stockpiled soils may have yielded different results in the re-establishment of microorganisms.

Stockpiling soil is a difficult endeavor on mined lands in Appalachia's steep terrain. Other amendment options, such as heavy mulching or sewage sludge applications, can be costly and may not be feasible for large scale reclamation operations. Hydroseeding for introducing lime, fertilizer, and seed is already a common practice in surface mine reclamation. In addition to soil stabilization and conditioning, non-competitive tree compatible vegetation may be useful in conjunction with the Forestry Reclamation Approach (FRA) for the establishment of microbial communities that aid in nutrient cycling.

The objective of this study was to determine the differences in biochemical properties of brown and gray sandstone mine soils and the impact of a hydroseed treatment.

4.2. Methods

4.2.1. Study Area

The study site for this investigation was Arch Coal's (formerly International Coal Group) Birch River Operation located near Cowen in Webster County, West Virginia. Details of the site are explained in Chapter 3.

4.2.2. Sampling

In May 2011, soil was collected from the top 15 cm of the mine soil surface and sieved with a 2mm screen into a 5-gallon bucket. Three samples were collected and composited from each experimental unit (experimental units are explained in Chapter 3). The shovel, bucket and sieve were cleaned and sterilized with a 10% ethanol solution between sampling of each experimental unit. Samples were stored in individual plastic bags in a sealed black plastic tub at 4°C until analysis took place in July. Before analyses, the needed amount of sample was weighed and allowed to incubate for 24 hrs in the dark at room temperature.

4.2.2. Soil Moisture

Soil moisture content was determined by a gravimetric method. Ten grams of field moist soil was weighed into aluminum weighing trays in triplicate for each soil. The weight of the sample was recorded and aluminum trays containing soil were placed in a drying oven set to 100°C. After 24 hours, the aluminum trays were removed from the oven and allowed to cool for 1 hr at room temperature. Trays and dried soil were weighed. The difference between field moist soil and dry soil samples was recorded as the water weight. Soil moisture content was expressed as the ratio of water weight to dry soil weight of each sample.

4.2.3. Soil Organic Carbon (SOC)

Total carbon was measured with a Leco TruSpec CHN elemental analyzer (LECO Corp. St Joseph, MI). Between 0.09 and 0.11 grams of air-dried soil were weighed into foil cups and combusted at 950°C. The amount of CO₂ evolved was measured with an infrared gas spectrometer and used to determine total combustible carbon.

The contribution of inorganic carbon (carbonates) to total carbon was determined by chemical oxidation of carbonates with a 1M HCl solution, a process also used by Insam and Domsch (1988) in a study which investigated SOC and microbial biomass carbon (MBC) on reclaimed mine sites. The procedure as described by Ussiri and Lal (2008) was followed for this experiment. Two grams of soil were weighed into 50-mL polypropylene centrifuge tubes and reacted with 20 mL of 1M HCl for 30 min on a reciprocating shaker. Samples were then centrifuged and decanted. This process was repeated twice more for a total of three HCl washes. After the three washes, samples were placed in a drying oven at 60°C for 48 hrs. Between 0.09 and 0.11 grams of oven-dried soil were then weighed into foil cups and C was measured by the Leco CHN analyzer. Inorganic carbon was calculated as the difference between total carbon and carbon evolved from samples reacted with HCl.

Geogenic carbon (coal carbon) was determined by a simple thermal oxidation found to be more effective and less involved than the method described by Ussiri and Lal (2008) and Keene (2010). One gram of dry HCl washed soil was weighed into ceramic crucibles and placed in a muffle furnace set at 340°C for 3 hrs. After this heating step, all carbon, except that in the form of geogenic carbon, should have thermally oxidized. Samples were weighed into foil cups,

combusted, and analyzed for carbon as the above mentioned samples. Soil organic carbon was calculated as the difference between total carbon minus geogenic and carbonate carbon.

4.2.4. Microbial Biomass Carbon (MBC)

Soluble carbon and microbial biomass carbon fractions of the soil were determined using the chloroform fumigation extraction method from Brookes and Joergensen (2006). Two sets of 10-g triplicate samples of field moist soil were weighed into 125-mL glass serum bottles. Weight was corrected for moisture. One set of triplicate samples was designated as a control and would not undergo chloroform fumigation. Control samples were extracted with 25 mL of 0.5M K_2SO_4 on a reciprocating shaker for 60 min. Samples were vacuum filtered through 0.45 μm Millipore filters, yielding a soil free extract which was frozen until analyzed using a Sievers 5310C Total Organic Carbon Analyzer (GE Analytical Instruments, Boulder, CO.) for total organic carbon.

For fumigated samples, a 3-mL glass vial with 2 mL of amylene stabilized chloroform was placed in each serum bottle. Airtight rubber stoppers were used to cap bottles. A vacuum was created by pulling air from each bottle with a vacuum pump. Samples sat for 24 hrs in the dark and then extracted, filtered and analyzed just as control samples were. Microbial biomass carbon was calculated as the difference between the control and fumigated samples divided by an extraction efficiency factor of 0.35.

4.2.6. Total Combustible Nitrogen (TCN)

Total Combustible Nitrogen (TCN) was measured with a Leco TruSpec CHN elemental analyzer (LECO Corp. St Joseph, MI). Between 0.09 and 0.11 grams of air-dried soil were weighed into foil cups and combusted at 950°C. The evolved nitrogen oxides and nitrogen gas

from the sample was reduced and measured with an infrared gas spectrometer to determine TCN. Nitrogen contributions from carboniferous material were determined by thermal oxidation just as coal carbon was determined.

4.2.7. Potentially Mineralizable Nitrogen (PMN)

Potentially Mineralizable Nitrogen (PMN) was determined using the anaerobic incubation method (Canali and Benedetti, 2006). Non-incubated control triplicate samples were created by weighing 16 grams (on a dry weight basis) of field moist soil and adding 40 mL of distilled deionized water (DIW) into 250-mL glass Erlenmeyer flasks. Soil was extracted with 40 mL of 2M KCl for 60 min on a reciprocating shaker. Supernatant was filtered through 0.45 μm Millipore filters and frozen until further analysis.

Incubated triplicate samples were created by weighing 16 grams (on a dry weight basis) of field moist soil into 50-mL polypropylene centrifuge tubes. Soil was suspended in 40 mL of DIW and incubated at 40°C for 7 days. Every 24 hrs during the incubation period soil was re-suspended in solution. After the incubation period, the soil-water solution was transferred to a 250-mL glass Erlenmeyer flask. Centrifuge tubes were rinsed four times with 2M KCl into the same Erlenmeyer flasks. Samples were extracted, filtered and stored as control samples were.

A colorimetric method described by Mulvaney (1996) was used to determine the amount of nitrogen in the form of ammonium (NH_4^+) present in the filtered supernatant. The difference between control and incubated samples was calculated and recorded as the PMN.

4.2.8. Herbaceous Cover

Herbaceous cover was measured using 1-m² quadrats in five random locations within each experimental unit. Herbaceous cover, litter cover, tree cover, and bare soil/rock were estimated and recorded as a percentage.

4.2.9. Data Analysis

Soil moisture, SOC, MBC, TCN, PMN, and herbaceous cover were analyzed by one-way ANOVA by mine soil type and hydroseed application. We used the R language and Environment for Statistical Computing for all the above analyses (R Development Core Team, 2011).

4.3. Results

Mine soil type (brown versus gray sandstone) had no significant effect on microbial biomass carbon (MBC) and potentially mineralizable nitrogen (PMN). Mean MBC values were the same in both mine soil types (Table 4-1). Hydroseed application had a significant effect on MBC and PMN (Table 4-1). Mean MBC was over two times higher in the hydroseed treatment with a mass of 16 mg kg⁻¹ compared to 6.8 mg kg⁻¹ in non-hydroseed plots. Mean PMN was greater in the hydroseed treatment (Table 4-1). Herbaceous cover was found to be 30% on hydroseed treatments, which was significantly higher than non-hydroseed treatments with a cover of 13% (Table 4-1). Brown sandstone had significantly greater carbon fractions except carbonate carbon than gray sandstone (Table 4.2). Coal fraction nitrogen was significantly higher in brown sandstone. Carbon and nitrogen fractions were not affected by hydroseed treatment. Both MBC:TC and PMN:TCN ratios were higher in the hydroseed treatment (Table 4.3), indicating that more C and N in this treatment were in the active fractions and more available for microbes and plants.

Table 4-1. Mean microbial biomass carbon (MBC), potentially mineralizable nitrogen (PMN) and percent herbaceous cover (HC) for mine soils after five growing seasons at the Birch River Operation in Webster County, WV.

Treatment		MBC	PMN	Herbaceous Cover
Mine Soils		--- mg kg ⁻¹ ---		--- % ---
	Brown sandstone	37	0.55	20
	Gray sandstone	37	0.45	20
Hydroseed				
	Hydroseed	44*	0.85**	30**
	Non-hydroseed	31	0.28	13

*means for main treatment factors are significantly different at $P < 0.1$

**means for main treatment factors are significantly different at $P < 0.001$

Table 4-2. Carbon and Nitrogen fractions in mine soil samples after five growing seasons at the Birch River Operation in Webster County, WV.

Treatment		Total C	Soil C	Carbonate C	Coal C	Total N	Soil N	Coal N
		----- mg kg ⁻¹ -----						
Mine Soils					--			
	Brown sandstone	1833**	878**	272	683**	90	77	14**
	Gray sandstone	1427	612	265	549	87	87	0.5
Hydroseed								
	Hydroseed	1668	805	232	630	72	66	5.8
	Non-hydroseed	1646	732	293	620	100	91	10

**means within main treatment factors are significantly different at $P < 0.01$

Table 4-3. MBC:Total Carbon (TC) and PMN:TCN ratios expressed as a percentage after five growing seasons at the Birch River Operation in Webster County, WV.

Treatment	MBC:TC	PMN:TCN
Mine Soils	----- % -----	
Brown sandstone	2.0	0.61
Gary sandstone	2.5	0.52
Hydroseed		
Hydroseed	2.6	1.18
Non-hydroseed	1.8	0.25

4.4. Discussion

It was expected that significant differences would be found between the two sandstone mine soils in regards to biochemical properties mainly because of the large differences between the substrates' chemical properties (Chapter 3). A study by Machulla et al. (2005) concluded that parent material was the principle factor effecting MBC in mine soils of lignite mines in Germany. In their study three types of mine soil were examined before and after reclamation with hay mulch. The lowest MBC was found in an unmulched mine soil similar to the brown sandstone mine soil used in our study. Soil texture of their material was described as a loamy sand with a rock fragment content of 39%, and soil pH was around 5. Their values for SOC, TCN, and extractable K and P were very similar to those of brown and gray sandstone mine soils at the Birch River site. Soil organic carbon in their sandy mine soil ranged from 3800 mg kg⁻¹ in the first cm from the surface to 500 mg kg⁻¹ 5 to 10 cm below the soil surface. TN ranged from 300 to 0 mg kg⁻¹. After reclamation with mulch, MBC increased from 9 mg kg⁻¹ to 148 mg kg⁻¹ and remained at a steady concentration for three years following reclamation. MBC in our study

(ranging from 31 to 44 mg kg⁻¹) was three times higher than their unamended mine soils, but considerably lower than their amended mine soils. In the Machulla study and another by Gildon and Rimmer (1993), soil moisture content of the mine soil material was found to be an important property affecting MBC. In our study, no significant differences were found between soil moisture content of the two mine soil types or the hydroseed treatment (data not shown). Although the mine soils at Birch River exhibited the usual differences observed in other studies with mine soils composed of brown and gray sandstone (Angel et al. 2008, Emerson et al. 2009), these mine soils were not dissimilar enough to directly or indirectly produce any differences in MBC. Showalter et al. (2010) similarly found that despite differences in soil chemical and physical properties, MBC and PMN in brown and gray sandstone materials were not significantly different. In their study, no differences were measured between MBC in brown and gray sandstone material planted with three types of hardwood trees. For the most part their bare sandstone mine soils were lacking in available N (Schoenholtz et al. 1992). Heterotrophic microflora and fauna are capable of utilizing geogenic carbon in mine soil materials but significant amounts of N in these materials are generally not available for utilization by plants or microbes (Waschkies and Hüttel, 1999). The PMN:TCN ratio of bare sandstone materials in our study were close to 50% less than the PMN:TCN ratio found in the hydroseed treatment. This indicates that much less of the N found in the soil was in the active fraction and was therefore not as available to plants and microbes (Stephens et al., 2001). A regression analysis by Showalter et al. (2010) showed that PMN was highly correlated to tree biomass and therefore the input of litter and nutrients was most likely the limiting factor of growth in mine soils. It could be that limited N mineralization was responsible for low MBC in the bare sandstone mine soils of our study. This is further supported by the slightly higher MBC:TC ratio found in the

hydroseed treatment. Again this higher ratio indicates that more carbon in the hydroseed treatment was in the active fraction (Insam and Domsch, 1988).

Hydroseed treatment did have a significant effect on biochemical properties of the mine soils. Past fertilization, vegetation growth and subsequent vegetation litter provided available N for microflora and fauna which contributed to the higher MBC found in the hydroseed treatments. A higher PMN:TCN indicated that more of the TCN in hydroseed treatments was available to microbes. Vegetation surveys quantified the differences in herbaceous vegetation between the hydroseed and non-hydroseed treatments. With this being the only difference between the treatments, it was assumed that herbaceous vegetation cover was an influential factor in MBC and PMN. Mummey et al. (2002) investigated biochemical properties and spatial relationships to plant communities. They discovered that MBC, SOM, and N depletions were stratified across the site and concentrated at the base of plant stems. A similar trend could be occurring at the Birch River site. In the bare sandstone treatments, barren areas were found between trees. Our sampling methods did not take this into account, as samples were taken randomly at varying distances from tree bases. We may have diluted our samples by mixing samples near trees with samples further away from the bases of trees thereby resulting in lower MBC and PMN. Had we sampled closer to tree bases, we may have found our MBC and PMN values to be more similar to our hydroseed treatments. In the hydroseeded areas of the plot, a more uniform plant cover was found with less exposed soil. Vegetation that rapidly decomposes and is recycled in mine soils appears to be beneficial for microbial activity. Herbaceous cover may promote a more homogenous soil environment which could promote root expansion by trees and shrubs (Mummey et al., 2002). Other studies on reclamation and biochemical properties have demonstrated the positive impact of mulching and other organic matter additions on biological

soil properties of reclaimed mine sites (Anderson et al., 2008; Machulla et al., 2005; Showalter et al., 2010).

This microbial study was conducted five years after trees were planted and hydroseeding was performed, and as such provided a snapshot evaluation of reclamation progress at the site. Future studies at this site documenting changes of biochemical properties over time would better assess the nutrient cycling capabilities and progress of reclamation at the site. In this manner, the success of reclamation practices and the return of ecosystem services could be evaluated. Other studies have examined these dynamic biochemical properties over time and demonstrated the development and evolution of microbial populations and diversity, which were used to indicate reclamation success on a site (Akala and Lal, 2001; Anderson et al., 2008; Insam and Domsch, 1988). According to a chronosequence study of reclaimed sites in West Virginia by Stephens et al. (2001), reclaimed mines saw a pulse in microbial activity and biomass in the first ten years after reclamation followed by a steady decline during the following years. This pulse was attributed to the rapid consumption of nutrients provided by fertilizers and the quick turnover by herbaceous vegetation. While PMN and MBC were currently higher in the hydroseed treatment, it is possible that this site was only experiencing a temporary pulse in microbial activity.

Hydroseeding at a rate of 35 kg ha⁻¹ with non-competitive tree compatible herbaceous vegetation (Table 3-2) and applying 336 kg ha⁻¹ of 10-20-10 NPK fertilizer had a significant effect on microbial biomass, but less so on tree growth and soil chemical and physical properties. This study showed that hydroseed application was a beneficial practice to enhance microbial development which can restore nutrient cycling abilities to FRA sites.

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