HARDWOOD TREE PERFORMANCE ON AMENDED BROWN AND GRAY MINE SPOILS AFTER FOUR YEARS[1]

C. Thomas and J. Skousen[2]

Abstract: 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, but advancements in technology and mining methods has accelerated the disturbance of valuable contiguous deciduous forests in the Appalachian region. Mountaintop mining has converted large expanses of forested mountaintops to rolling pasture and hay land. Once thought to be of economic value, these pasture/hay lands were unmanaged and 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 amendments selection and placement and planting of appropriate herbaceous and tree species. In order to evaluate tree growth on selected spoils with various amendments, a 3-ha demonstration plot was created at ICG-Eastern's Birch River mine in West Virginia. The plot is comprised of two exclusive areas of oxidized (brown) and un-oxidized (gray) sandstone substrates. Portions of each area were amended with bark mulch and/or hydroseeded with fertilizer and herbaceous species, creating a total of eight treatments. The study area was planted with a variety of hardwood tree species on 2.4-m centers. Soil chemical properties and tree survival and growth were evaluated for four years beginning in 2007. After four years, hydroseeding had no effect on soil chemical properties. Soil chemistry strongly depended on sandstone type and mulch amendment. The pH of brown sandstone without bark mulch application was 4.9. Soil pH for brown sandstone with mulch and all gray sandstone treatments ranged from 7.2 to 7.8. The largest average tree volume, 1098 cm^3, was recorded on treatments with brown sandstone and bark mulch. Tree growth on gray sandstone was the lowest. Interaction between sandstone type and mulch was most influential on tree growth. Four years after reclamation, hydroseeding at a rate of 28 lbs ac^{-1} had no effect on tree growth. Interaction between sandstone type and mulch was most influential on soils chemical properties. No treatment was found to have an effect on tree survival. Survival of all treatments ranged from 77 to 100%. In conclusion, tree growth on brown sandstone outperformed gray. After four years, hydroseeding had no effect on tree growth 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.

Additional Key Words: gray sandstone, brown sandstone, tree survival, tree volume, bark mulch, hydroseeding

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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. Mountaintop mining methods have converted large expanses of forested mountain tops to rolling pasture and hay lands. Once thought to be of economic value, these pasture/hay lands were unmanaged and have been left abandoned to revert to shrub land dominated by invasive non-native species (Torbert and Burger, 2000). Due to excessive soil compaction and heavy herbaceous cover, natural plant community succession to hardwood forests is slow. Invasive species, both shrubs and herbaceous plants, compete too fiercely for nutrients and available water. Combined with the harsh soil conditions and heavily compacted mine soils, colonization and growth of trees are 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. Rapid regeneration depends on well suited soils. 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. .

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). 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.

Substrate selection has shown to be a controlling factor is the success of post mining land use. Studies by McFee et al. (1981) and Casselman et al. (2006) found that substrates derived from shale and siltstone result in 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 (Haering et al., 2004). Un-oxidized sandstone, commonly referred to as gray sandstone, is generally more abundant and is located closer to the bottom-most coal seam. 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 (Haering 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.

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 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 will 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 not affect 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 spoil characteristics and improve mine soil properties through such mechanisms as nitrogen fixation and microbial growth. 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). Decreased vegetation has shown to result in greater success of tree survival and growth (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 be helpful in 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 (Wick et al., 2010; Anderson et al., 2008). Studies by Ringe et al. (1988 and 1989) have 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. Our main objective was to evaluate tree growth as a result of various combinations of these factors. We have also examined soil properties related to these treatments.

The objective of this study was to evaluate tree growth and survival on oxidized and un-oxidized sandstone substrates with and without herbaceous ground cover and bark mulch treatments, and to monitor potential effects of treatments on soil chemical characteristics.

Methods:

Study Area

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

In November 2006, a 3-ha plot was created using two types of sandstone overburden. Half of the area was constructed with brown sandstone, the other half with gray sandstone. Overburden materials were end-dumped into conjoining piles that were approximately 1.5-m deep throughout. To limit compaction, a bulldozer took 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 layer of bark mulch was applied to a portion of both sandstone types (Fig.1). Following mulch application, approximately 8,000 bare root seedlings were planted on 2.4-centers by a professional planting crew. A list of tree species and their respective portion of the total is in Table 1. The following fall, ends of the plot were hydroseeded with a seed mix of ground compatible herbaceous vegetation (Table 2), and fertilized at a rate of 300 lbs acre^{-1} of 10-20-10 NPK. The treatments were as follows (Fig. 1):

1. brown sandstone (B)
2. brown sandstone-bark mulch (BM)
3. brown sandstone-hydroseeded (BH)
4. brown sandstone-hydroseeded, bark mulch (BHM)
5. gray sandstone (G)
6. gray sandstone-bark mulch (GM)
7. gray sandstone-hydroseeded (GH)
8. gray sandstone-hydroseeded, bark mulch (GHM)

Table 1: Species planted on the site and their relative abundance.

Species	**Total Number Planted**	**% of Total Planted**
Black cherry	850	11
Northern red oak	850	11
Sugar maple	850	11
White ash	850	11
White oak	850	11
Black locust	800	10
Pitch X loblolly pine	800	10
Yellow poplar	600	8
Sycamore	450	6
White pine	400	5
Dogwood	350	4
Eastern redbud	350	4
Total	**8,000**	**100**

Table 2: Herbaceous plant species in seed mix with respective seeding rate.

Species	**Rate**
	lb/acre
Birdsfoot trefoil	10 lb/ac
Kobe lespedeza	5 lb/ac
Ladino clover	3 lb/ac
Orchard grass	5 lb/ac
Perennial ryegrass	5 lb/ac
Red top	2 lb/ac
Weeping lovegrass	2 lb/ac
Total	**32 lb/ac**

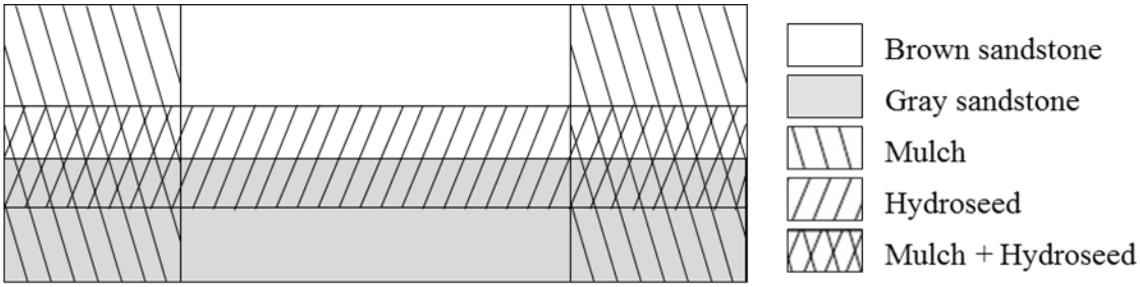

Figure 1: Plot layout.

Trees

To assess tree growth, we established 3-m wide transects varying in length in order to span the width of the plot. Approximately 12% of the research plot area was sampled. 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 the first weeks of August, every year from 2008 to 2010. Volume of tree biomass was calculated with the following equation:

$$\text{Tree volume (cm}^3\text{)} = \text{Height (cm)} \times \text{Diameter}^2 \text{ (cm}^2\text{)} \qquad \text{(Emerson et al., 2009)}$$

Tree survival was calculated by finding the difference between the number of trees sampled the first year, 2008, and the last year, 2010.

Soils

The top 15 cm of soil from the surface was collected from four random locations within transects on each treatment in July of 2007 to 2010. In mulched areas, we sampled the mineral by scraping aside the bark mulch on the surface of the soil. These samples were used for chemical 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 and greater). 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 30 mL of Mehlich 1 extracting solution (0.05M HCl and 0.025M H_2SO_4). Supernatant was analyzed for Al, Ba, Ca, Mg, Mn, P, K, and Zn 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.

Data Analysis

We constructed 5 general linear models, representing working hypothesis to predict tree volume and 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 recommendations. The five regression models predicting volume were (1) sandstone type only, (2) mulch application only, (3) hydroseeding only, (4) an interaction of sandstone type and mulch application, and (5) an interaction of sandstone type and hydroseeding. A null model was also included in the analysis, fitting a model to the intercept only without regard to treatment effects. Models that ranked lower than the null model were likely not responsible for differences in the data. Delta AIC values corrected for sample size bias (ΔAICc) was used to rank models and the model weight was used to evaluate the ability of the model to correctly predict volume (Burnham and Anderson, 2002). The mean volume of trees located in each experimental unit was used in the analysis. Not every species was represented in all treatments. Therefore, mean volume was calculated independent of species. Box plots were used to examine trends in the data.

The same working models were used to evaluate the influence of treatment on survival. We calculated survival by the difference of individuals occupying the site between 2008 and 2010. 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 redundant variables were excluded if r >0.95. 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 regression models for predicting selected soil chemical properties were (1) sandstone type only, (2) mulch application only, (3) hydroseeding only, (4) an interaction of sandstone type and mulch application, (5) an interaction of sandstone type and hydroseeding and (6) a null model. We used the R language and Environment for Statistical Computing for all the above analyses (R Development Core Team, 2011).

Results:

Tree Growth

The interaction model had the highest empirical support for being the best model in the set. We found a sandstone type by mulch application interaction influenced tree growth the most. This interaction as a predictor of tree volume ranked the highest in the set of models, followed by sandstone type (SS) alone and mulch application (M) alone (Table 3). This (SS*M) interaction model had 22 times the support of models predicting volume by sandstone type or mulch application alone. Both of these models had a weight of 0.06 compared to 0.88 of the interaction. Sandstone and mulch were both important in predicting tree volume but their interaction was more influential on volume than either independent of the other. Models including the hydroseeded treatment as a predictor of tree volume ranked lowest and below the null model indicating that these models were insignificant and that this treatment had little if any empirical support for influence on tree growth. Weights for these models were less than 0.01.

Table 3: Tree growth and survival model rankings.

Variables	**Model**	**K**	**AICc**	**ΔAICc**	**Model Weight**	**Cumulative Weight**	**Log Likelihood**
Volume							
	SS*M	4	543.50	0.00	0.88	0.88	-267
	SS	3	549.66	6.15	0.04	0.92	-271
	M	3	549.89	6.38	0.04	0.96	-271
	1	4	550.16	6.65	0.03	0.99	-270
	SS*H	2	553.85	10.34	0.01	1.00	-274
	H	3	554.93	11.43	0.00	1.00	-274
Survival							
	1	2	349.44	0.00	0.40	0.40	
	M	3	350.41	0.97	0.24	0.64	-172
	H	3	351.68	2.24	0.13	0.77	-171
	SS	3	351.76	2.32	0.12	0.89	-172
	SS*M	4	352.88	3.44	0.07	0.96	-172
	SS*H	4	354.15	4.71	0.04	1.00	-171

There was considerable overlap of tree volume for areas of brown and gray sandstone with and without mulch application (Fig. 2). Gray sandstone without mulch exhibited consistently lower growth. Areas with mulch application had more variation in growth data (Fig. 2).

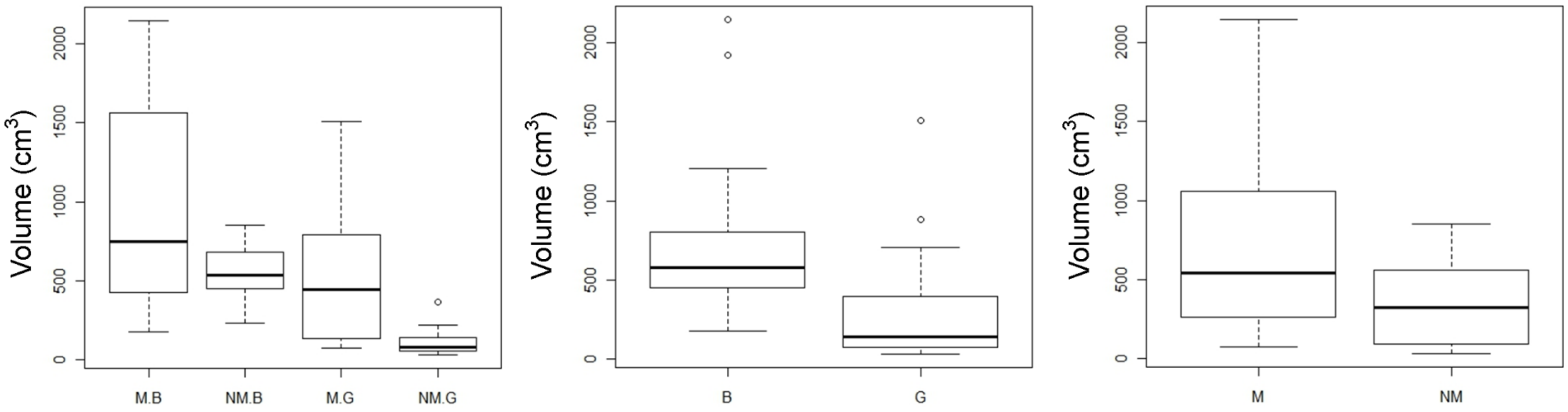

Figure 2: Box plots of tree volumes for areas of brown (B) and gray (G) sandstone with (M) and without (NM) mulch application.

The highest mean tree volume was 1098 cm^3 (Table 4). This was the mean volume for trees growing in brown sandstone with mulch application. The lowest mean (70 cm^3) was for trees growing in gray sandstone without amendments. These volumes were based on treatment areas and did not exclude hydroseeded treatments. When ignoring hydroseeded treatments, the highest and lowest volumes were still found in areas of brown sandstone with mulch and gray sandstone with mean volumes of 973 and 134 cm^3, respectively (Table 4).

Table 4: Mean tree growth and survival for each treatment.

Treatment	**Volume**		**Survival**	
	--------------*cm^3*----------		-------------*%*-----------	
B	549	571*	96	90*
BM	1098	973**	100	95**
BH	591		81	
BHM	764		86	
G	70	134*	89	86*
GM	744	539**	92	87**
GH	197		83	
GHM	196		77	

* treatments of sandstone and sandstone with Hydroseeded combined
** treatments of sandstone with Mulch and sandstone with Hydroseeded and Mulch combined

Tree Survival

We found no strong empirical support for any of our a priori models in our candidate set for survival. Analysis indicated that no treatment was strongly influencing tree survival. The null model ranked highest in the set (Table 3). However, mulch application appeared to still contain a large amount of the information. The null model had less than two times the weight of the mulch application, which only had roughly two times the weight of the hydroseeded application and sandstone type models. The weights were 0.42, 0.24, 0.13, and 0.12, respectively (Table 3). The interaction models had little weight but not enough to dismiss them. Mean survival ranged from 77 to 100% survival and from 85 to 95% when ignoring hydroseeded treatments (Table 4).

Soils

Of the soil chemical properties recorded the most important in explaining variation in the data set included Al, Fe, Mn, Ca, K, P, Zn, pH, and electrical conductivity (EC). Magnesium was highly correlated with Ca and therefore removed from the data set to reduce information redundancy. PCA revealed that P, Ca, K and EC all loaded strongly in the positive direction and Zn, Al and Fe loaded strongly in the negative direction on principle component (PC) 1 (Table 5 and Fig. 3). Mn and pH loaded strongly on PC2 in the positive direction.

Table 5: PCA results for first 3 PCs.

Variables	**PC1**	**PC2**	**PC3**
Eigenvalue	5.42	1.59	1.03
% Variation	60.25	17.67	11.54
% Cumulative variation	60.25	77.92	89.40
Al	-0.64	0.16	-0.71
Fe	-0.83	0.49	0.02
Mn	0.46	0.76	-0.39
Ca	0.96	0.11	-0.16
K	0.93	0.13	-0.10
P	0.70	-0.45	-0.48
Zn	-0.80	0.02	-0.07
pH	0.53	0.71	0.32
EC	0.96	-0.11	0.10

Interaction between sandstone type and mulch had the strongest influence on soil properties, with the exception of Zn, K, and Mn (Table 6). These were most strongly influenced by mulch treatment. No model including hydroseeded treatment had a high enough weight to support the hypothesis that it was potentially influencing soil chemical properties (Table 7). In addition, models including hydroseeded application ranked below the null model. Form this it can be assumed that any differences in chemical properties resulting from hydroseeding were no longer realized after four years.

Values for pH appeared to be significantly lower in areas of brown sandstone without mulch application compared to areas of gray sandstone regardless of mulch application (Fig. 4). The mean value of pH for non-amended brown sandstone was 4.9. Ignoring hydroseeded treatment, it was 5.2 (Table 4). All other treatments had mean pH values higher than 6.5 but lower than 8.0.

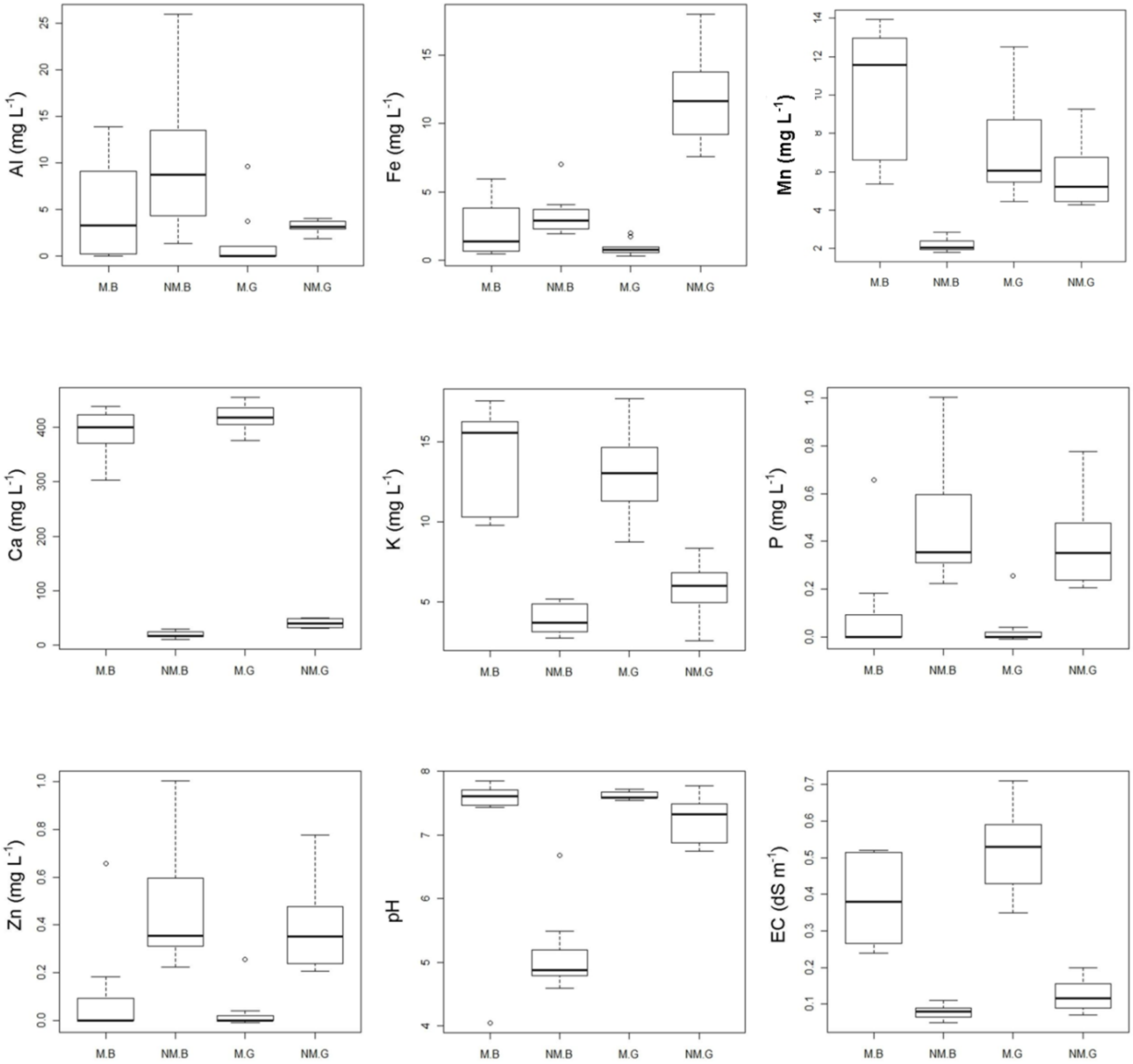

Figure 3: Box plots of soil chemical properties for areas of brown (B) and gray (G) sandstone with (M) and without (NM) mulch application.

Al, Fe, P and Zn appeared to have higher values in areas that received no mulch application (Fig. 4). Of these, concentrations of Zn and P in areas of bark mulch application, regardless of sandstone type, were noticeably higher. Fe levels were consistently higher in areas of brown sandstone without mulch application. There were no large differences in Al concentration among treatments, but areas of mulched un-oxidized sandstone appeared to be consistently lower with respect to Al concentration. Mn, Ca, and K all showed opposite trends (Fig. 3). Concentrations of all three of these elements were considerably higher in areas with the mulch application regardless of sandstone type.

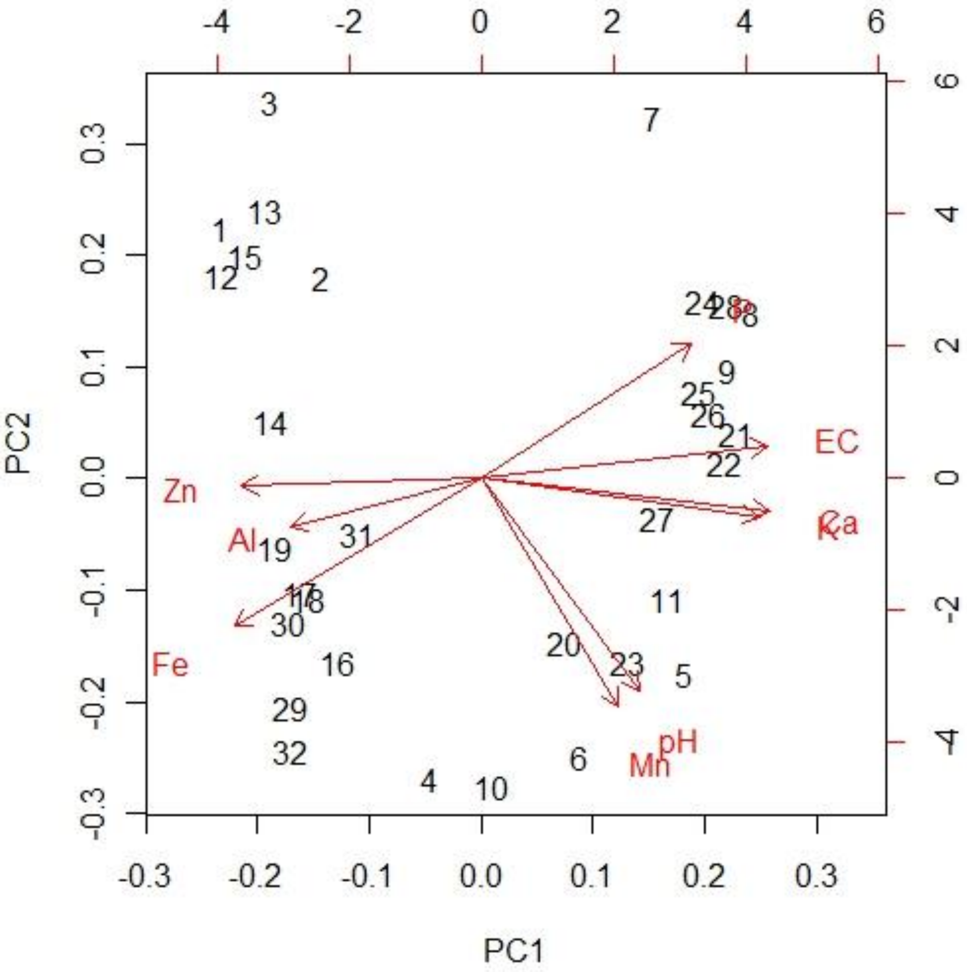

Figure 3: PCA biplot with numbers representing sample number and vector direction and length indicating variable trend and strength. Points grouping on the left are all samples taken from mulched areas. Points on right are all samples taken from non-mulched areas.

Table 6: Soil property model rankings. Only the top three ranked models are displayed.

Property	Model	K	AICc	ΔAICc	Model Weight	Cumulative Weight	Log Likelihood
Mn	M	3	164.38	0.00	0.78	0.78	-78.7
	SS*M	4	218.68	2.56	0.22	1.00	-78.7
	1	2	289.16	14.0	0.00	1.00	-86.9
Al	SS*M	4	201.01	0.00	0.51	0.51	-95.7
	SS	3	201.95	0.93	0.32	0.83	-97.5
	M	4	204.57	3.56	0.09	0.92	-97.5
K	M	3	153.29	0.00	0.76	0.76	-73.2
	SS*M	4	155.62	2.33	0.24	1.00	-73.1
	1	2	197.03	43.70	0.00	1.00	-96.3
Ca	SS*M	4	305.40	0.00	0.91	0.91	-147
	M	3	310.00	4.59	0.09	1.00	-151
	1	2	430.77	125	0.00	1.00	-213
Zn	M	3	-7.92	0.00	0.63	0.63	7.38
	SS*M	4	-6.83	1.08	0.37	1.00	8.15
	1	2	10.29	18.2	0.00	1.00	-2.98
P	SS*M	4	75.51	0.00	0.96	0.96	-33.1
	M	3	81.84	6.32	0.04	1.00	-37.5
	SS	3	94.37	18.9	0.00	1.00	-43.7
Fe	SS*M	4	174.45	0.00	0.91	0.91	-82.4
	M	3	179.11	4.66	0.09	1.00	-86.1
	SS	3	193.88	19.40	0.00	1.00	-93.5
EC	SS*M	4	-55.75	0.00	0.92	0.92	32.6
	M	3	-50.96	4.79	0.08	1.00	28.9
	1	2	-7.64	48.10	0.00	1.00	6.0
pH	SS*M	4	86.54	0.00	0.99	0.99	-38.5
	SS	3	97.01	10.4	0.01	1.00	-45.1
	M	3	98.10	11.5	0.00	1.00	-45.6

Table 7: Mean values for extractable elements, soil pH, and electrical conductivity in 2010 for all treatments.

	B	**B***	**BM**	**BM****	**BH**	**BHM**	**G**	**G***	**GM**	**GM****	**GH**	**GHM**
Element		--*mg/L*--										
Al	6	10*	6	5**	14	3	3	3*	4	2**	3	0
Fe	2	3*	1	2**	4	2	10	12*	1	1**	14	1
Mn	2	2*	11	10**	2	9	5	6*	10	8**	7	6
Ca	21	19*	392	391**	18	389	36	41*	409	419**	45	427
K	4	4*	14	14**	4	15	5	6*	14	13**	7	12
P	1	1*	1	1**	1	0	-	2*	6	0**	3	0
Zn	0.6	0.4*	0.2	0.1**	0.4	0.0	0.3	0.3*	0.1	0.1**	0.5	0.0
Property												
pH	4.90	5.16*	6.70	7.18**	5.30	7.60	7.40	7.24*	7.60	7.62**	7.10	7.60
		--*dS/m*--										
EC	0.10	0.08*	0.40	0.38**	0.10	0.40	0.10	0.12*	0.50	0.51**	0.20	0.50

** treatments of sandstone and sandstone with H combind*

*** treatmeats of sandstone and H and sandstone with H and M combind*

Discussion:

Trees

In this study, the interaction between sandstone type and mulch application was the most influential factor controlling tree growth. Sandstone type and mulch application separately had little explanatory ability. The sandstone types may become the more dominate influence in growth as trees become more deeply rooted in the mineral soil. Although not investigated, it is speculated that the mulch is the rooting media right now for trees and not the sandstone type placed beneath the mulch layer. However, as mulch decomposes and becomes more incorporated into the mineral soil, the current trend may continue. Differences between mulch and no 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. Logistics of planting did not allow for random planting resulting in tree groupings of the same species and uneven species distribution over the entire plot. Species were not represented in all treatments or over represented in others. Due to differences in growth habit, it is possible that averaged volumes were inflated or underinflated based on species distribution. Looking at individual species may have been more appropriate but was not possible in this study because of the small sample sizes and lack of replication.

Overall, trees grown in brown sandstone had a higher mean volume than those grown in gray sandstone. Other studies have seen similar trends in gray and brown sandstone in relation to tree growth (Emerson et al., 2009; Angel et al., 2006; Showalter et al., 2010). Favorable chemical and physical properties of brown sandstone are typically cited as the cause. Trends in brown and gray sandstone chemical properties observed in this study are in line with others (Emerson et al., 2009; Angel et al., 2006; Haering et al., 2004; Showalter et al., 2010). Brown sandstone derived topsoils are usually more similar to native undisturbed soils in Appalachia. These undisturbed soils are mildly acidic and contain high concentrations of Fe and Al and low concentrations of base cations (Farr et al., 2009; Stark et al., 2004).

Treatments effects did not appear to be a factor in tree survival. While lower survival rates were observed in non-amended gray sandstone, there was no conclusive evidence that sandstone type influenced survival. Visual observations in the field indicated that the quality of trees in gray stone was less. Trees in all treatments showed signs of wildlife browsing.

The ranking and weight of models including hydroseeded application indicated that a seeding rate of 28 lb ac^{-1} will not prohibit or constraint tree growth. Any effect of fertilization or hydroseeding on tree growth was not observed 4 years after reclamation.

Soil

The elevated levels of Ca and Mg in mulched areas were most likely caused by limestone gravel present in the mulch. This also accounted for the elevated EC and pH of the mineral soil below the mulch application. EC values were still not high enough to negatively impact tree growth (Cummins et al., 1965). Slightly elevated levels of Ca in gray sandstone were a result of carbonates (Haering et al., 2004). The presence and weathering of carbonates also accounted for the higher pH and EC of gray sandstone treatments.

According to tree data, it appeared that these elevated elements were potentially having a positive effect on tree growth. The reduction of Al, Fe, P and Zn in mulched areas could be a result of the formation of metal complexes with organic matter. 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). Four years after reclamation, any effects of hydroseeding on soil chemical properties have been overridden by natural processes.

Conclusions:

In this study, application of bark mulch had positive effects on tree growth. Survival was not influenced by any treatment. Four years after reclamation, hydroseeding at a rate of 28 lbs ac^{-1} had no effect on tree growth or soil properties. Interaction between sandstone type and mulch was most influential on tree growth and soil chemical properties. Sandstone type alone 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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