GROWTH OF THREE APPALACHIAN HARDWOOD SPECIES IN DIFFERENT MINE SPOIL TYPES WITH AND WITHOUT TOPSOIL INOCULATION[1]

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Abstract. The goal of many landowners who own reclaimed mined land is to restore the diverse mixed mesophytic forest for environmental, economic, and cultural reasons. However, native hardwoods tend to grow poorly on mined sites due to their physical, chemical and biological mine spoil properties. A 4 x 2 x 3 factorial greenhouse experiment was conducted with one-year-old seedlings. We examined the suitability of four growth media: forest topsoil (FT), weathered sandstone (WS), unweathered sandstone (US), and unweathered shale (UH), as well as the effects of inoculation with topsoil (none verses inoculated), on the growth of three native hardwood species: *Fraxinus americana*, *Q. rubra*, and *L. tulipifera*. Tree growth, foliar nutrients, and soil properties were measured and characterized. The WS was the mine spoil material most conducive to growth for *F. americana* and *Q. rubra*. *L. tulipifera* did not respond to any treatments. Foliar nutrient analysis indicated that adequate nutrition of *Q. rubra* was independent of spoil type ($p = 0.49$), *F. americana* was somewhat dependent on spoil type for nutrient uptake ($p =<0.0001$), and *L. tulipifera* was highly dependent, ($p < 0.0001$). Topsoil inoculation significantly increased growth on the UH spoil type, but not the US or WS spoil types. Topsoil inoculation significantly increased the number of herbaceous plants growing in the pots and improved foliar nutrient indices in *F. americana* and *L. tulipifera*. Many properties, such as pH, microbial activity, and water availability of the WS more closely approximated the control soil than the sandstone or shale. The results of this study show that trees are sensitive to spoil type and that certain spoil types should be selected during the reclamation process. Topsoil inoculation should also be considered as it may increase tree growth on some spoil materials, improve tree nutrition and help return the diverse native plant population that was present prior to mining.

Additional Key Words: mine reclamation, reforestation, topsoil substitutes.

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Introduction

The native hardwood forest of Appalachia consists of a rich collection of vegetation that plays an essential role in the economy, esthetics, environmental biodiversity, and culture of the Appalachian Mountains. Many of the late-successional hardwoods are valuable timber species, playing an important role in the timber economy of the area, while other tree and herbaceous species have cultural and environmental importance. Many of the understory plants are gathered for medicine or food, such as ginseng and ramps (Duke, 1997; Jones and Lynch, 2002). Basket weaving and doll making are also examples of nontimber forest products in Appalachia (Alexander et al., 2002). The diverse wildflower populations are important esthetically and environmentally. From the overstory come sourwood and basswood honey, which are valued for their unique specialty flavors (Hill, 1998). Large mast trees such as oaks and hickories are not only important timber species but supply food for wildlife. Many of the state flowers and trees of the seven states in the Appalachian region are symbols of the diversity and beauty of the native hardwood forest in this region. They include flowering dogwood (*Cornus florida*), tulip poplar (*Liriodendron tulipifera*), hemlock (*Tsuga canadensis*), rhododendron (*Rhododendron maximum*) and mountain laurel (*Kalmia latifolia*).

This mixed mesophytic forest is dominated by beech (*Fagus grandifolia*), basswood (*Tilia americana*), sugar maple (*Acer saccharum*), sweet buckeye (*Aesculus octandra*), red oak (*Quercus rubra*), white oak (*Q. alba*), and hemlock (*Tsuga canadensis*). Birch (*Betula lenta*)), black cherry (*Prunus serotina)*, cucumber tree (*Magnolia acuminate*), white ash (*Fraxinus americana*) and red maple (*A. rubrum*) also comprise a large portion of the forest, with black gum (*Nyssa sylvatica*), black walnut (*Juglans nigra*) and hickories (*Carya*) present, but not abundant (Braun, 1950). In addition to these 15 species are another 22 species that occur in different regions (Braun, 1950). This forest is unique in its diversity and is an invaluable asset to the people of the region.

The mixed mesophytic forests are currently being eliminated over large areas by surface mining. Over 500,000 ha have been affected by strip mining in the Appalachian region since the implementation of SMCRA in 1978 (OSM, 1999). Since 1978, these areas are graded and hydroseeded with non-native herbaceous vegetation, reclaiming them to grassland. However, there has been a recent shift towards reforestation of reclaimed mined land (OSM, 1999). These reforestation efforts, although a step closer to the return of the native forest, usually involve planting monocultures of early successional species. For example, black locust is able to survive and grow (Vogel and Berg, 1973; Filcheva et al., 2000), but planting this species results in forest stands with little or no diversity. Because of the competitive herbaceous vegetation and the physical and chemical properties of the mine spoils, many of the native species of the mixed mesophytic forest are unable to establish themselves where they once occurred in abundance. Although early successional species such as black locust, autumn olive, and Virginia pine may return some forest cover, the value of the forest and its future potential, economically, environmentally, culturally, and esthetically, is largely degraded.

When attempts have been made to plant a more diverse array of native hardwoods, including the oaks, sugar maple, and black cherry on reclaimed mined sites, their survival and growth is often poor. Mined sites have many of the characteristics typical of primary successional sites. The two most important factors dictating plant establishment in primary succession are the ability to seed into the area and the subsequent ability of the plant to germinate, emerge, and grow in the given harsh conditions (Chapin, 1993). Some early-successional plant species that are wind- and bird-disseminated and have an opportunistic growth habit are better adapted for reclaimed strip mines. However, many of the later-successional native species that occur in the mixed mesophytic forest are less likely to become established on mined sites, and when they do, they do not grow well because they cannot tolerate mine spoil conditions.

Primary successional species are well adapted to seeding into the center of even large mines this with small winged or cottony seeds. However, late-successional species often have large heavy seeds that do not travel the distances needed to seed into these areas. An alternative seed source is the seed bank of the native forest topsoil. This may be an invaluable source for the return of these late successional native species. After only one growing season, seed banks from native topsoils placed on mine spoils have been shown to produce 1.9×10^6 shoots ha^{-1}, with a diversity of 134 taxa (Farmer et al., 1982). Seed banks may not contain all the target late-successional forest species, but they are of a later sere and are higher in native species than the primary successional seeds that are brought with the wind. Seed banks may thus lead to a much higher seedling survival rate and faster development of a native ecosystem.

The other aspect of establishment on these sites is the ability of plants to survive and grow in the spoil medium. There are a variety of spoils placed on the surface during reclamation, and few are selected to maximize tree growth. Mine spoils have highly variable physical and chemical properties, ranging from very acid pyritic materials to alkaline shale. Compared to native soils, mine spoils can have poor chemical properties such as extreme pH, high soluble salts, and low levels of nutrients (Torbert et al., 1990). They can also have poor physical properties such as low moisture content or porosity, poor structure, or high bulk density, and high levels of rock fragments (Bussler et al., 1984). Within this array of spoil types, some are probably more suited to the growth of native forest species.

With current reclamation practices in this region consisting of hydroseeding with grasses and legumes or planting with early successional trees, the return of native forests may take several hundred years. In order to more quickly restore the late-successional forest, it may be possible to skip the first few stages of succession. The overall goal of this research program is to reduce the successional timescale by creating a hospitable environment for reforestation and natural forest processes for late-successional species. This may require a spoil medium conducive to the reestablishment and growth of later successional species, returning the soil seed bank, and inoculating the spoil with forest soil organisms.

Therefore, as part of our work toward this broad goal, the objectives of this study were: (1) to determine the relative suitability of three different mine spoil types for hardwood growth; (2) to determine if topsoil inoculation improves growth of several native hardwood species; and (3) to evaluate the establishment of native herbaceous understory plants from spoils inoculated with topsoil.

Methods and Procedures

Soil and Treatment Characterization

Mine spoils for this study were collected with the help of the Pritchard Mining Co., from its mine located south of Charleston, West Virginia. This surface mine uses a combination of contour and mountaintop removal mining. The area was forested with the Appalachian oak forest type (Braun, 1950) prior to mining. Current reclamation practices at this mine involve returning a variety of rock types to the surface, grading, planting with a non-native grass and legume species mix and planting a variety of tree species. No effort is made to select specific topsoil substitutes for trees, which is typical for reclamation throughout the Appalachian coalfields.

Three different mine spoils and undisturbed native topsoil were collected for this greenhouse experiment in March 2004. The three spoil types, weathered sandstone (WS), unweathered sandstone (US), and unweathered shale (UH), were taken from various levels of the Kanawha geologic formation, and all are used during reclamation as topsoil substitutes depending on their presence during mining. The forest topsoil (FT) was used as the control and was collected from the upper 30 cm of soil of the adjacent forest stand.

WS occurs close to the surface and is exposed to chemical weathering, creating an oxidised material with a tanish, redish, or yellowish hue that can range from 10R to 2.5Y and with a high chroma (Munsell, 1994). The WS used in this study was 10YR 6/8. US and UH, on the other hand, occur deeper within the geologic profile and are not exposed to chemical weathering. The iron in these materials remains mostly reduced resulting in colors with a chroma of 1. The US is usually a lighter grey while UH is darker. The US collected for this study was 5Y 6/1 while the UH was 2.5Y 3/1.

The Kanawha formation is 210 m thick at its north end and becomes progressively thicker, reaching 600 m at its southern reach in West Virginia (Blake et al., 1994). The sampled area is on the shallower end of this spectrum in Boone County, West Virginia. In West Virginia, this formation runs through Kanawha, Boone, Fayette, Raleigh, Logan, Wyoming, Mingo, and McDowell Counties in the southwestern part of the state. It is comprised of sandstones, siltstones, shale and coal. Because of its numerous coal seams, it is intensively mined.

The native soils on the site are typical of the area. The site is located in an upland region of Clymer-Dekalb-Gilpin soil types, which is strongly sloping to very steep, well drained, and acid, (Soil Survey, 1981). The majority of the slopes were very steep Clymer-Dekalb complexes before mining occurred. Clymer is a fine-loamy, mixed, mesic Typic Hapludult, while Dekalb is a loamy-skeletal, mixed, mesic, Typic Dystrochrept (Soil Survey, 1981). Forest site index for red oak ranges from 65 to 75. The original soil is rarely used as the final growth medium during reclamation. Soils are usually not stockpiled or preserved and are lost deep within the mine when spoils are returned during reclamation.

WS is the bedrock located directly beneath the soil solum. This weathered rock is the parent material of these forest soils and is normally exploited by deep-rooted trees. It has a pH comparable to the native topsoil, is easily weathered when placed on the surface, and occasionally has trace amounts of native forest topsoil mixed with it when it is used on the surface as a topsoil substitute.

US is also used as a topsoil substitute during reclamation. It contains limestone concretions that are common in shale siltstone and sandstone marine deposits in the area (Blake et al., 1994). Limestone characteristics suggest that the pH of this soil is much higher than the topsoil. Calcareous sandstone also occurs at the base of these marine layers.

UH is common in the geologic profile, occurring in several shale members located above the coal seams. Similar to the US, UH is a marine deposit and may have many similar characteristics (Blake et al., 1994). It is, however, much finer-grained, creating silty and clayey mine soil material.

Greenhouse Methods

Each of three tree species, *Fraxinus americana* L., *Liriodendron tulipifera* L., and *Quercus rubra* L., were planted in the three mine spoil types, WS (weathered sandstone), US (unweathered sandstone), and UH (unweathered shale), along with the control, FT, (forest topsoil) (Table 1). Half of the 7.57 L pots were inoculated with 2.5 cm of native topsoil, which was spread on the surface, creating a 1:214 topsoil to spoil ratio. This 4 x 2 x 3 factorial design was replicated 10 times, for a total of 240 pots.

Table 1. Greenhouse experiment layout with a 4 x 2 x 3 factorial design across FT (forest topsoil), WS (weathered sandstone), US (unweathered sandstone), and UH (unweathered shale) that were inoculated or not inoculated and planted to three different tree species.

Treatment	FT	WS	US	UH
Not inoculated	*L. tulipifera* *Q. rubra* *F. americana*	*L. tulipifera* *Q. rubra* *F. americana*	*L. tulipifera* *Q. rubra* *F. americana*	*L. tulipifera* *Q. rubra* *F. americana*
Inoculated with native topsoil	*L. tulipifera* *Q. rubra* *F. americana*	*L. tulipifera* *Q. rubra* *F. americana*	*L. tulipifera* *Q. rubra* *F. americana*	*L. tulipifera* *Q. rubra* *F. americana*

The surfaces of all pots were covered with a hydroseed paper mulch to simulate field conditions and to decrease potential contamination from pot to pot. A watering treatment of 1.5 L was applied to each pot once a week. Trees were planted in May 2004 and were harvested in October 2004.

Laboratory Methods

In order to determine which properties of the spoil types most influenced tree growth, the physical, chemical and biological properties were characterized. Soil samples were collected from the pots in October when trees were harvested. The ten replications of each treatment combination were divided into four groups of two or three pots per group. Soil from pots of each group was combined, creating four composite samples per treatment combination. Mulch was removed from all pots before combining, but topsoil on the surface of the inoculated pots was mixed into the composite samples. Subsamples from each composite sample were sieved through a 2-mm sieve, kept at 4ºC, and processed within 2.5 weeks of collection. An adenosine triphosphate (ATP) procedure was used to estimate microbial activity (ATPlite, 2002). The procedure was modified as follows for the analysis of soils. Soil was placed in a saline solution and shaken for an hour to put microbial populations into solution. The samples were then centrifuged at 1000 rpm to remove particulate matter while allowing microbes to remain in solution. This solution was then used in the standard ATP procedure (ATPlite, 2002). Dehydrogenase concentration was found through a 2,3,5-Triphenyltetrazolium chloride (TTC) indicator (Tabatabai, 1982). Microbial biomass was measured by chloroform fumigation (Anderson and Domsch, 1978; Gregorich et al., 1990; Jenkinson and Powlson, 1976).

The remainder of the composite samples were dried and sieved through a 2-mm sieve, and an array of physical and chemical properties was measured. Bulk density was determined by weighing the contents of the pot and calculating the volume of the soil; coarse fragment content was determined by weight. Soil particle size was determined using the hydrometer method (Bouyoucos, 1936). Total soluble salts were measured with an electrical conductivity meter (Bower and Wilcox, 1965), and pH was measured in a 2:1 water:soil suspension using a pH glass electrode. Nitrogen availability was measured via aerobic incubation (Bremmer 1965a) and inorganic nitrogen was measured using a KCl extraction method (Bremmer, 1965b). Total nitrogen and carbon were found using a carbon nitrogen analyzer (Vario MAX, 2000 Elementar Americas, Inc., Hanau, Germany). Exchangeable cations were extracted using the ammonium acetate method and determined on an ICP spectrophotometer (SpectroFlame Modula Tabletop ICP, 1997, Spectroanalytical instruments, Germany; Thomas, 1982).

Leaves were harvested from each tree in mid-August from the upper portion of the crown, dried at 65°C for 7 days, and ground to pass a 1-mm sieve. Foliar nitrogen content was found using a C-N analyzer (Vario MAX 2000 Elementar Americas, Inc., Hanau, Germany). Potassium, Ca, Mg, Mn and P were determined by dry-ashing the samples, extracting using a 6N HCl solution, and analyzing the extracts with an ICP spectrophotometer referenced above (Jones and Steyn, 1973).

Tree height was measured at the beginning and end of the growing season to determine incremental stem growth. At the end of the growing season, stems and roots were harvested, dried at 65°C for 1 week. Incremental stem growth for that growing season was separated from stems and weighed to determine dry incremental stem biomass. Total root biomass was also found.

Data Analysis

This experiment was a completely randomized 4 x 2 x 3 factorial design that was statistically examined using an analysis of variance (SAS, 2004). The dependent variables tree growth and spoil physical, chemical and biological properties were compared among the following independent variables: spoil types, inoculated and un-inoculated pots, and species.

Results

Tree Growth Response

Spoil type had a significant effect on tree height ($p = 0.0013$), incremental biomass ($p < 0.0001$), and root biomass ($p < 0.0001$) (Table 2). Species was also significant for all dependent variables ($p < 0.0001$). The main effect of inoculation was not significant for any dependent variable, although the interaction of spoil and inoculation was significant for incremental height ($p = 0.0167$), and the interaction of spoil and species was significant for incremental biomass ($p < 0.0001$) and root biomass ($p < 0.0001$).

Table 2. Significance of main effects and interactions of spoil type, topsoil inoculation, and species on tree growth.

Treatment	Incremental Height (cm)	Incremental Biomass (g)	Root biomass (g)
Spoil	0.0013^{***}	$<0.0001^{***}$	$<0.0001^{***}$
Species	$<0.0001^{***}$	$<0.0001^{***}$	$<0.0001^{***}$
Inoculation	0.2592	0.3311	0.9782
Spoil x Inoculation	0.0167^{**}	0.6691	0.6822
Spoil x Species	0.2254	$<0.0001^{***}$	$<0.0001^{***}$
Inoculation x Species	0.5505	0.6549	0.4006
Spoil x Inoculation x Species	0.7964	0.9056	0.6955

Significance at the 0.1, 0.05, and 0.01 levels is marked by *, **, or ***, respectively.

Incremental tree height of the UH_{non-I} (non-inoculated unweathered shale) was about two-thirds that of the FT_{non-I} (Fig. 1). Inoculation of the UH_I increased the incremental height by about 50%. Incremental height of the US_I treatment was also less than that of the FT treatments. The heights of the WS treatments were no different than those of the FT treatments.

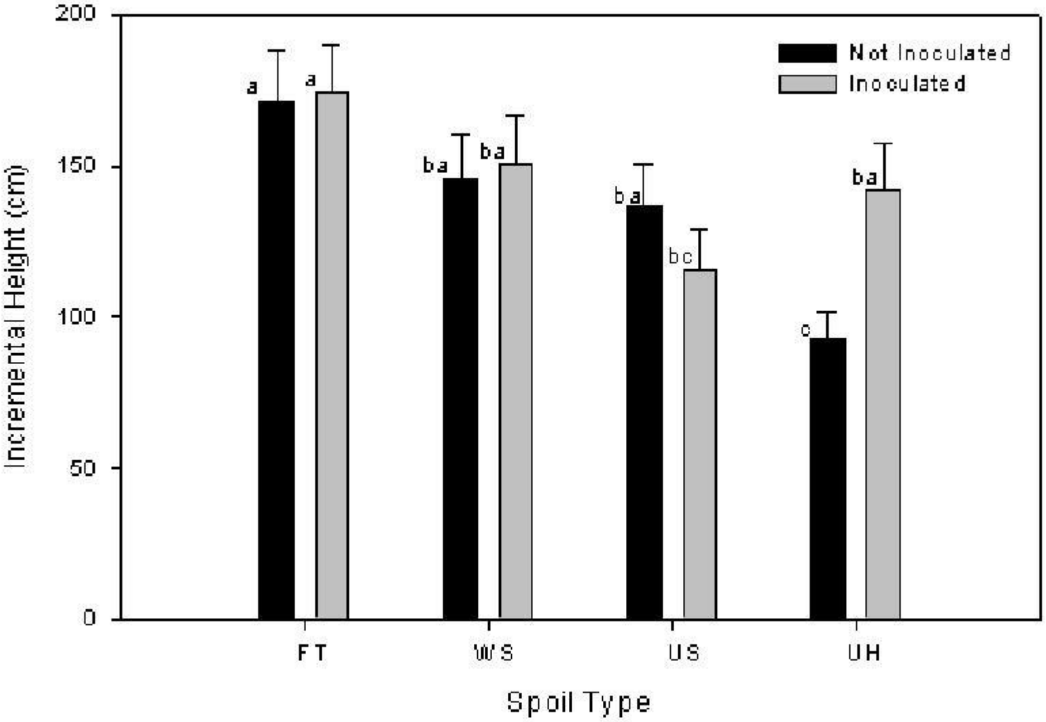

Figure 1. Effect of mine spoil type and topsoil inoculation on incremental height of three native hardwood species. Different letters signify significantly different means using Fisher's LSD (0.05).

There was a significant interaction between spoil type and species for both shoot and root biomass. Shoot and root biomass of *F. americana* was different among nearly all treatments. Shoot biomass responded in the order FT > WS > US = UH (Fig. 2). Root biomass responded to spoil type treatments in the order FT>WS>US>UH.

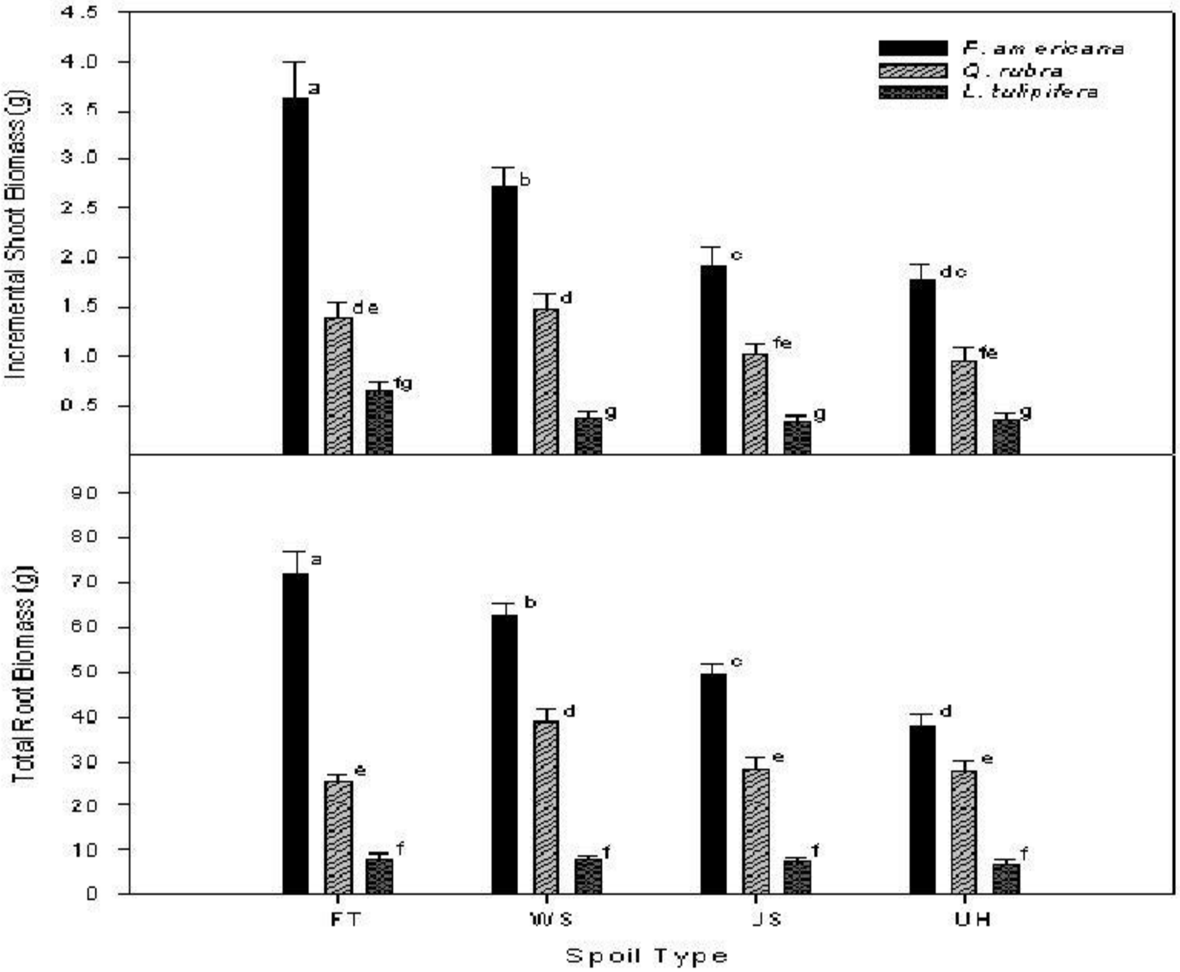

Figure 2. Interaction between spoil and topsoil inoculation on means and standard errors of shoot and root biomass. Different letters signify significantly different means using Fisher's LSD.

Overall, *Q. rubra* grew at half the rate of *F. americana* and was less sensitive to spoil type. Shoot growth of *Q. rubra* responded to treatments in the order FT=WS, but WS > US = UH. For root growth, the order was WS > FT = US = UH. Shoot and root growth of *L. tulipifera* was considerably less than the other two species and was similar among spoil type treatments.

There was a significant interaction (p = 0.003) between spoil type and the number of native, volunteer, herbaceous plants per pot. There was nearly an average of four volunteer herbaceous plants in the FT pots, one plant in every other WS pot, and an occasional plant in the US and UH spoil types (Fig 3). Topsoil inoculation greatly increased herbaceous plants in the WS, US, and UH pots to two to three per pot on average.

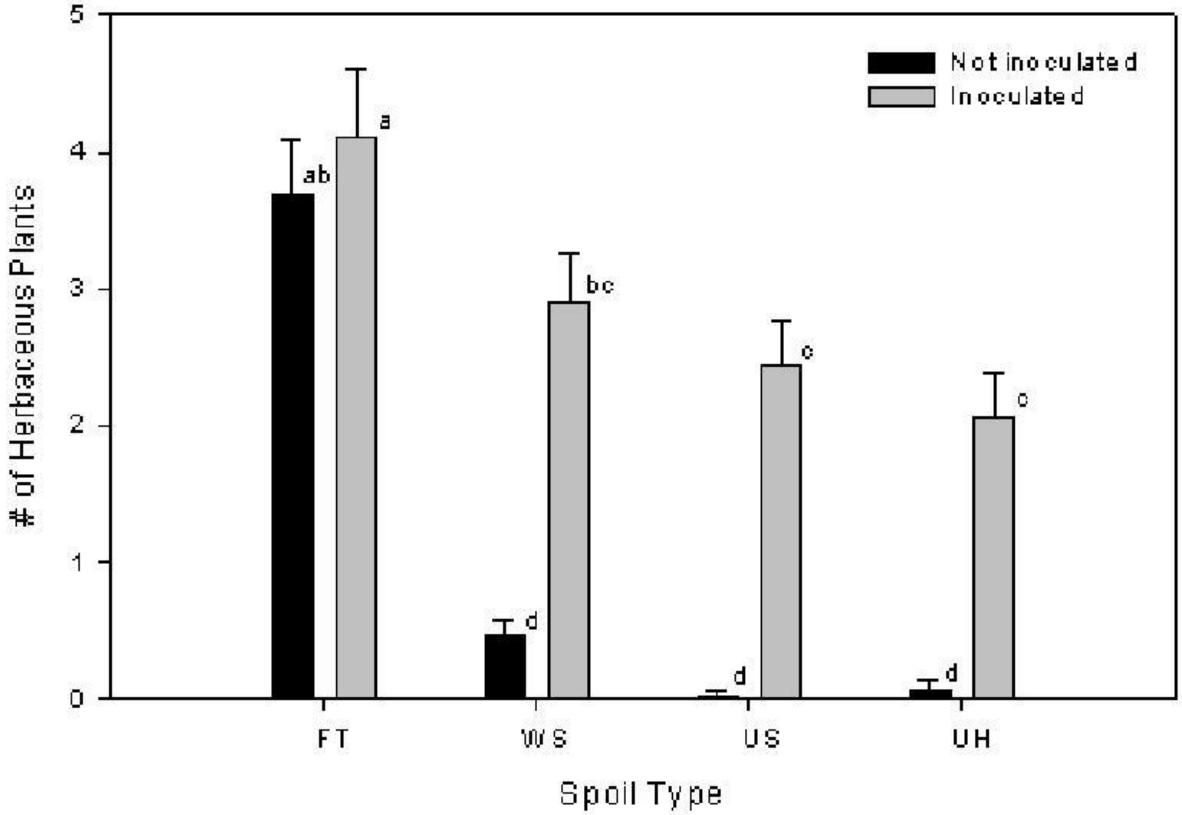

Figure 3. Number of understory plants found in three spoil types and a native control soil that were either inoculated or not inoculated with topsoil. Different letters signify significantly different means using Fisher's LSD.

Soil Characterization

Almost all spoil physical, chemical and biological properties tested were significantly different across spoil types (Tables 3-5). Physical properties were characterized prior to setting up the experiment. The WS had the highest fine earth fraction (57%), followed by the FT (41%), US (38%) and UH (32%). The FT had the highest silt plus clay content (48%) followed by the UH (45%). Silt plus clay content of the US (21%) was half that of the FT and the UH, while the WS was intermediate at 33%. The wilting point and H_2O availability of the UH (4.8% and 5.06%) were half that of the FT (9.51% and 10.20%). The WS had an even lower wilting point (3.66%), but higher water availability (7.6%) than the UH. The US had the lowest wilting point and water availability (1.3% and 4.86%).

Table 3. Mean values of physical soil properties for three mine spoils and a control and for inoculated verses not inoculated spoils. Different letters signify significantly different values based on Fisher's LSD.

Measurement	FT	WS	US	UH
% Fines	41^{b}	57^{a}	38^{b}	32^{b}
% Silt + Clay[†‡]	47.82^{a}	33.15^{c}	21.04^{d}	44.84^{b}
Wilt pt (% by wt)[†‡]	9.51^{a}	3.66^{c}	1.30^{d}	4.80^{b}
H_2O Retention (% by wt)[†‡§]	10.20^{a}	7.60^{ba}	4.86^{b}	5.06^{b}

[†] represents significant correlation of a soil property with incremental stem height.

[‡] represents significant correlation of a soil property with incremental stem biomass.

[§] represents significant correlation of a soil property with total root biomass

Table 4. Mean values of chemical soil properties for three mine spoils and a native control soil and for inoculated verses not inoculated spoils. Values are on a whole soil basis. Different letters signify significantly different values based on Fisher's LSD test.

Soil Property		FT	WS	US	UH	Mean
pH[†‡§]	Not Inoc.	5.23^{e}	5.53^{d}	8.86^{a}	8.39^{b}	**7.00**
	Inoc.	5.19^{e}	5.59^{d}	8.17^{b}	7.58^{c}	**6.63**
	Mean	**5.21**	**5.56**	**8.515**	**7.985**	
EC (dS m^{-1})	Not Inoc.	0.229	0.123	0.303	0.616	**0.318**^{a}
	Inoc.	0.243	0.131	0.331	0.508	**0.303**^{a}
	Mean	**0.236**^{b}	**0.127**^{c}	**0.317**^{b}	**0.562**^{a}	
Exchangeable Acidity ($cmol^{+}$ kg^{-1})[†‡§]	Not Inoc.	0.62	0.32	0.00	0.00	**0.23**^{a}
	Inoc.	0.66	0.24	0.00	0.00	**0.23**^{a}
	Mean	**0.64**	**0.28**	**0.00**	**0.00**	
CEC ($cmol^{+}$ kg^{-1})	Not Inoc.	1.50^{b}	1.14^{d}	0.71^{f}	1.60^{a}	**1.23**
	Inoc.	1.51^{b}	1.22^{c}	0.87^{e}	1.56^{a}	**1.29**
	Mean	**1.51**	**1.18**	**0.79**	**1.58**	
KCl Extractable Inorganic N (mg kg^{-1})	Not Inoc.	27.72	19.32	10.05	9.93	**16.76**^{a}
	Inoc.	20.10	16.28	15.77	12.46	**16.15**^{a}
	Mean	**23.91**^{a}	**17.80**^{ab}	**12.91**^{b}	**11.20**^{b}	

[†] represents a significant correlation of a soil property with incremental stem height.

[‡] represents a significant correlation of a soil property with incremental stem biomass.

[§] represents a significant correlation of a soil property with total root biomass.

Table 5. Mean values of biological soil properties for three mine spoils and a control and for inoculated verses not inoculated spoils. Values are on a whole soil basis. Different letters signify significantly different values based on Fisher’s LSD.

Measurement		FT	WS	US	UH	Mean
Microbial Biomass (chloroform fumigation mg kg^{-1}) †‡	Not Inoc.	1.17	0.20	0.10	0.10	**0.39**
	Inoc.	1.45	0.50	0.28	0.28	**0.63**
	Mean	**1.31** ^{a}	**0.35** ^{b}	**0.19** ^{b}	**0.19** ^{b}	
Dehydrogenase (mg TPF kg^{-1})†‡	Not Inoc.	90.10^{a}	2.17^{d}	0.41^{f}	0.79^{e}	**23.37**
	Inoc.	90.17^{a}	11.58^{b}	0.72^{e}	6.42^{c}	**27.22**
	Mean	**90.14**	**6.875**	**0.565**	**3.605**	
ATP(light response)†‡§	Not Inoc.	1536.55 ^{a}	249.66 ^{c}	156.96 ^{d}	214.82 ^{dc}	**539.50**
	Inoc.	1461.45^{a}	427.99^{b}	208.81^{d}	444.52^{b}	**635.69**
	Mean	**1499**	**338.83**	**182.89**	**329.67**	

† represents significant correlation of a soil property with incremental stem height.

‡ represents significant correlation of a soil property with incremental stem biomass.

§ represents significant correlation of a soil property with total root biomass.

Mine soil pH ranged from 5.19 to 8.86 across treatments. The pH of the WS (5.56) was only slightly higher than that of the FT (5.21), while the US and UH were very alkaline (8.86 and 8.39, respectively). Topsoil inoculation neutralized the alkaline spoils slightly to pH 8.17 for the US and 7.58 for the UH.

Soluble salt content ranged from 0.127 dS m^{-1} to 0.562 dS m^{-1}. The EC of the UH (0.616 dS m^{-1}) was almost three times as high as that of the FT (0.236 dS m^{-1}). The US (0.317 dS m^{-1}) was comparable in salinity to the FT (0.236 dS m^{-1}), while that of the WS (0.127 dS m^{-1}) was slightly lower.

Exchangeable acidity ranged from 0 to 0.64 cmol^{+} kg^{-1}. Neither the UH nor the US had any exchangeable acidity due to their high level of alkalinity. The FT had 0.64 cmol^{+} kg^{-1} of charge due to exchangeable acidity, while WS had only half that amount (0.28 cmol^{+} kg^{-1}). Topsoil inoculation did not affect exchangeable acidity on any of the spoil types.

The CEC ranged from 1.60 cmol^{+} kg^{-1} to half that amount (0.71 cmol^{+} kg^{-1}) across treatments. CEC of the UH (1.60 cmol^{+} kg^{-1}) was similar to that of the FT (1.50 cmol^{+} kg^{-1}), while that of the WS was slightly lower (1.14 cmol^{+} kg^{-1}) and that of the US was less than half (0.71 cmol^{+} kg^{-1}). Topsoil inoculation increased the CEC of the WS and US slightly, to 1.216 and 0.87 cmol^{+} kg^{-1}, respectively.

Salt-extractable available nitrogen levels ranged widely across spoil types, from 9.93 to 27.72 mg kg^{-1}. Compared to the FT (23.91 mg kg^{-1}), available N was about half that amount in the US (12.91 mg kg^{-1}) and UH (11.2 mg kg^{-1}), while that of the WS was intermediate (17.80 mg kg^{-1}) and not different from the other treatments. Topsoil inoculation had no effect on N levels for any of the soil types.

Microbial biomass, dehydrogenase level, and ATP level were highest on the FT (Table 5). Microbial biomass ranged from 1.31 to 0.19 mg kg^{-1} across treatments. The WS, US and UH all had very low levels, 0.35, 0.19 and 0.19 mg kg^{-1}, respectively, which were only a fraction of the level on the FT (1.31 mg kg^{-1}). Inoculation did not affect microbial biomass. Dehydrogenase and ATP levels also ranged an order of magnitude, from 90.17 mg kg^{-1} and 1536.55 to 0.41 mg kg^{-1} and 214.82, respectively. Levels of ATP and dehydrogenase were highest on the FT (90.17 mg kg^{-1} and 1536.55), followed by the WS (2.17 mg kg^{-1} and 249.66), which had levels that were only a fraction of that of the FT. UH levels were slightly lower (0.79 mg kg^{-1} and 214.82), and US had very low levels (0.41mg kg^{-1} and 156.96). Inoculation increased dehydrogenase levels over five times on the WS, from 2.17 to 11.58 mg kg^{-1}, and on the UH from 0.79 to 6.42 mg kg^{-1}, but did not affect the US. ATP levels doubled due to inoculation on the WS from 249.66 to 427.99, and increased on the UH from 214.82 to 444.52; they remained unchanged on the US.

Correlations to Tree Growth

Many physical, chemical, and biological soil properties were significantly correlated with tree growth across all three species. However, the relative importance of properties differed somewhat among species.

For *F. Americana*, the physical properties, wilting point and water retention, were positively correlated with incremental stem height and biomass as well as total root biomass (Table 6). Total root biomass was also positively correlated with percent coarse fragment content, while incremental stem biomass was correlated with percent silt plus clay.

All chemical variables except CEC were correlated with growth of *F. americana* pH and EC were negatively correlated with incremental stem growth, biomass and total root biomass. Exchangeable acidity and extractable N were positively correlated with incremental stem growth, incremental stem biomass, and total root biomass of *F. americana*. Dehydrogenase and ATP levels were positively correlated with incremental stem height, biomass, and total root biomass.

Table 6. Relationship of mine soil properties and foliar nutrient concentrations to growth of *F. americana*.

Property	Incremental Stem Height (cm)		Incremental Stem Biomass (g)		Total Root Biomass (g)	
	Corr. Coeff.	P value	Corr. Coeff.	P value	Corr. Coeff.	P value
% Fines	0.1831	0.3158	0.2773	0.1245	0.4411	0.0115**
% Silt + Clay	0.2538	0.1611	0.3854	0.0294**	0.2214	0.2232
Wilt pt (% by wt)	0.4992	0.0036***	0.6629	<0.0001***	0.5580	0.0009***
H_2O Retention (% by wt)	0.6085	0.0002***	0.7951	<0.0001***	0.8086	<0.0001***
PH	-0.4994	0.0042***	-0.6852	<0.0001***	-0.7462	<0.0001***
EC (dS m^{-1})	-0.3442	0.0580*	-0.4458	0.0120**	-0.6438	<0.0001***
Ex Acidity (cmol+ kg^{-1})	0.6169	0.0002***	0.7982	<0.0001***	0.7990	<0.0001***
CEC (cmol^{+} kg^{-1})	0.0792	0.6719	0.1804	0.3314	0.0082	0.9650
Available N (mg kg^{-1})	0.4196	0.0168**	0.3996	0.0235**	0.4271	0.0148**
Dehydrogenase (mg TPF kg^{-1} 24h^{-1})	0.6902	<0.0001***	0.8323	<0.0001***	0.7783	<0.0001***
ATP (light level)	0.6121	0.0003***	0.7725	<0.0001***	0.7316	<0.0001***

*, **, *** represent significance at the 0.10, 0.05, and 0.01 levels, respectively.

Q. rubra growth was well correlated with soil properties (Table 11/7). The physical property, percent fines, was positively correlated with all three growth variables, incremental stem height, incremental stem biomass and total root biomass, while incremental stem height and biomass were also positively correlated with water retention, and total root biomass was negatively correlated with wilting point. Similar to *F. americana*, stem height and biomass of *Q. rubra* was negatively correlated with pH and EC and positively correlated with exchangeable acidity. Incremental stem height and biomass were also correlated with ATP level, but not dehydrogenase activity.

Table 7. Relationship of mine soil properties and foliar nutrient concentrations to growth of *Q. rubra*.

	Incremental Stem Height (cm)		Incremental Stem Biomass (g)		Total Root Biomass (g)	
Property	Corr. Coeff.	p value	Corr. Coeff.	p value	Corr. Coeff.	p value
% Fines	0.4248	0.0154**	0.4875	0.0047***	0.3946	0.0254**
% Silt + Clay	0.0863	0.6387	0.0431	0.8148	-0.2807	0.1196
Wilt pt (% by wt)	0.2051	0.2601	0.2024	0.2665	-0.2980	0.0976*
H_2O Retention (% by wt)	0.3994	0.0236**	0.4444	0.0108**	-0.0916	0.6180
PH	-0.4984	0.0037***	-0.5267	0.0020***	-0.1005	0.5843
EC (dS m^{-1})	-0.4447	0.0108**	-0.4545	0.0090***	-0.1288	0.4822
Ex Acidity ($cmol^+ kg^{-1}$)	0.3648	0.0401**	0.4024	0.0224**	-0.1599	0.3820
CEC ($cmol^+ kg^{-1}$)	0.0806	0.6612	0.0729	0.6918	-0.1863	0.3074
Available N (mg kg^{-1})	0.1865	0.3069	-0.0365	0.8426	-0.2240	0.2179
Dehydrogenase (mg TPF kg^{-1} $24h^{-1}$)	0.2607	0.1496	0.2440	0.1784	-0.2530	0.1624
ATP (light level)	0.3045	0.0902*	0.3164	0.0777*	-0.2765	0.1255

*, **, *** represent significance at the 0.10, 0.05, and 0.01 levels, respectively.

Although growth differences of *L. tulipifera* were slight, they were well correlated with soil properties (Table 8). Percent silt plus clay, wilting point, and water retention were all positively correlated with incremental stem height and incremental stem biomass. Soil pH was negatively correlated with both incremental stem height and incremental stem weight, but not root biomass. Exchangeable acidity was positively correlated with incremental stem height and biomass, while CEC was positively correlated with incremental stem height only. All three microbial indicators were positively correlated with incremental stem height and incremental stem biomass.

Discussion

Effect of Spoil Type

This study showed that spoil growth medium plays a critical role in tree growth and success of native hardwoods on reclaimed strip mine sites. Based on the growth response of *F. americana* and *Q. rubra*, WS (weathered sandstone) was a superior medium for tree growth over US (unweathered sandstone) or UH (unweathered shale). Both tree species had greater stem and root biomass on the WS than on the other spoils. *L. tulipifera* did not show a growth response to any treatment. This may be because *L. tulipifera* is very sensitive to site quality and is very site specific even on undisturbed soils (Beck, 1990).

Table 8. Relationship of mine soil properties and foliar nutrient concentrations to growth of *L. tulipifera*.

	Incremental Stem Height (cm)		Incremental Stem Biomass (g)		Total Root Biomass (g)	
Property	Corr. Coeff.	P value	Corr. Coeff.	P value	Corr. Coeff.	P value
% Fines	-0.1060	0.5636	0.0191	0.9175	0.1393	0.4470
% Silt + Clay	0.4096	0.0199**	0.3394	0.0574*	-0.0904	0.6226
Wilt pt (% by wt)	0.5268	0.0020***	0.5173	0.0024**	0.0872	0.6352
H_2O Retention (% by wt)	0.4453	0.0107**	0.5207	0.0022***	0.2228	0.2203
PH	-0.3279	0.0669**	-0.4071	0.0208**	-0.1448	0.4290
EC (dS m^{-1})	0.0308	0.8673	-0.1114	0.5438	-0.1964	0.2813
Ex Acidity ($cmol^+$ kg^{-1})	0.4743	0.0061***	0.5396	0.0014***	0.2278	0.2106
CEC ($cmol^+$ kg^{-1})	0.3159	0.0782*	0.2309	0.2036	-0.1828	0.3168
Available N (mg kg^{-1})	-0.0037	0.9840	0.0384	0.8345	0.1700	0.3522
Microbial Biomass (chloroform fumigation mg kg^{-1})	0.5578	0.0009***	0.4869	0.0047***	0.1546	0.3981
Dehydrogenase (mg TPF kg^{-1} $24h^{-1}$)	0.4372	0.0124**	0.4720	0.0064***	0.0990	0.5900
ATP (light level)	0.5126	0.0027***	0.5238	0.0021***	0.0943	0.6078

*, **, *** represent significance at the 0.10, 0.05, and 0.01 levels, respectively.

The larger growth response of *F. americana* and *Q. rubra* on the WS may be due to a number of soil physical, chemical, and biological properties that differentiate the growth media. The higher percent fines and higher water retention more closely approximated the FT, creating a physical environment with a more balanced water/air ratio, which is more conducive to tree growth. The lower pH, higher microbial activity, and to some extent, higher nutrient availability also created an environment more conducive to tree growth (Tables 3-5). Many of these soil properties were correlated with incremental stem height and biomass as well as total root biomass of some or all tree species, further supporting that these properties were influencing tree growth (Tables 6-8).

The low percent coarse fragments of the WS compared to the US, UH, or even the FT created a larger rooting medium (Table 3). Root growth of *F. americana* and all growth parameters of *Q. rubra* were positively correlated with percent fines, but *L. tulipifera* was not, suggesting that other factors were having a greater influence on the growth of this species (Tables 6-8). The higher water retention of the WS and FT improved water availability between watering events. The US and UH, on the other hand, may have become droughty due to their lower water retention. Water retention did correlate well with all growth parameters of *F. americana* and to incremental tree height and incremental biomass of both *Q. rubra* and *L. tulipifera*, further supporting its importance to tree growth.

Rodrigue and Burger (2002) found water/air balance an important factor affecting a variety of eastern hardwood species growing on mined land in a seven-state region. Coarse fragment content and available water holding capacity were the second and third most important variables in their regression analysis of tree growth on mined sites. High amounts of rock fragments lead to a decrease in the fine earth available for exploitation by tree roots, which leads to a reduction in nutrient and water availability (Torbert et al., 1985; Childs and Flint, 1990; Thurman and Sencindiver, 1986; Rodrigue and Burger, 2004).

Percent silt plus clay and wilting point may also have been important factors due to their association with soil water/air balance. These physical properties also correlated well with growth of *F. americana*, and *L. tulipifera*, but not as well to growth of *Q. rubra* in this study. Percent silt plus clay and wilting point were highest on the FT, which may have led to the measured improvement in tree growth. However, these properties were not distinguishing factors of the WS from the other spoils and were most likely not the determining soil factors differentiating tree growth on the WS, US, and UH.

Chemical properties that may have played a role in growth of trees in this experiment include pH and nutrient levels (Table 4). The pH of the WS was slightly acidic, similar to the pH of the FT, compared to the basic pH's of the US and UH. The three native species in this study grow naturally on soils with pH around 5, and may have adaptations that favor this pH over more alkaline materials.

Soil reaction is widely documented as playing an important role in nutrient availability and toxicity in forest soils (Fisher and Binkley, 2000). In southwest Virginia, Showalter et al. (2005) found a negative correlation between white oak (*Q. alba*) growth and increasing pH level across a variety of mine spoil types that ranged in pH from 3.2 to 7.8.

On a site in the Virginian Appalachians, Torbert et al. (1990) found that pitch x loblolly hybrid pine had much higher growth on acidic sandstone (pH = 5.7) compared to alkaline siltstone (pH = 7.1). Pines usually tolerate more acidic soils than hardwoods (Fisher and Binkley, 2000). However, the soils of Appalachian hardwood forests are largely acidic (Hicks, 1998), showing that native hardwoods of this area are also adapted to moderately acidic soils.

In central Ohio, Kost and colleagues (1998) found that black pine (*Pinus nigra* Arnold) had improved survival after nine years with the addition of a low-pH (6.8), low coarse fragment content (26%) topsoil to a high-pH overburden (7.4) with a higher coarse fragment content (51%). Tree growth was compared to that on overburden alone (survival was 60% compared to 37%). Green ash (*F. pennsylvanica* Marsh), black pine, and silver maple (*A. saccharinum* L.) had better growth rates on added topsoil (136, 165, and 57 cm) compared to overburden alone (102, 116, and 41 cm). The success of these species could be attributed to either the lower coarse fragment content or lower pH, or a combination of the two. These studies corroborate the tree/mine soil property relationships found in our experiment; that is, native hardwoods appear to prefer soils with a moderately low pH similar to native soils of the area.

Indirect factors may have also played a role in the growth differences measured in this study. The lower pH of the WS (5.56) may have been better for the growth of native soil organisms. Wei-Chun Ma (1989) found that earthworm populations in fly ash-amended mine soils in the Netherlands were negatively impacted by high pH's. Four- to five-year-old sites amended with fly ash with a pH of 8.2 had 49 worms m^{-2}; 15- to 18-year old sites with a pH of 7.9 had 265 worms m^{-2}; and control sites had a pH of 7.6 and 333 worms m^{-2}. Other soil fauna such as millipedes and isopods were also negatively impacted by increasing amounts of fly ash in soil mixtures. Microorganisms may also be influenced by pH and can shift in composition based on the acidity or alkalinity of the medium.

Increased pH was negatively correlated with growth of all three species in this study, further showing the importance of a moderately acid pH in the range of 4.8 to 6.5 for optimum growth. It is clear from the results of this study that alkaline soil reaction above pH 7.5 is detrimental to tree growth.

Mineralizable N is essential for successful tree growth (Fisher and Binkley, 2000) and is often very low on fresh spoil materials (1.52 mg kg^{-1}) (Schoenholtz et al., 1992). Reeder (1977) also found very low levels of N mineralization in five mine spoils (0 to 11 mg kg^{-1}) from Colorado and Wyoming compared with the native topsoil (57 mg kg^{-1}). In Virginia, Schoenholtz et al. (1992) found that replacement of topsoil on mine sites increased mineralizable soil N levels from 45.76 mg kg^{-1} to 66.95 mg kg^{-1} but did not lead to improved growth of pitch x loblolly hybrid pine (*P. rigida* L. x *P. taeda* L.) or herbaceous vegetation. Growth appeared to be more a function of water availability than of nitrogen, with woodchip applications improving tree growth and increasing water availability.

These studies support the findings from our study that N levels are clearly deficient on mine spoils but that other spoil properties are more important to tree growth. However, although the effects of low available nitrogen may have been masked by the more influential effects of soil physical properties, it is clear that nitrogen levels were deficient.

All materials were also deficient in available P, having a negative impact on growth of all species across all treatments. The importance of sufficient P for tree growth is well established (Fisher and Binkley, 2000), suggesting that P fertilization is an important reclamation practice for all materials that are to be used for a native tree growth medium. However, it is also apparent that the WS was a superior medium because of higher levels of available P for the growth of *F. americana*.

Microbial populations were higher on the WS over the US or the UH, suggesting a greater return of the below-ground ecosystem. Microbes are a crucial component for N and P availability on newly reclaimed sites. Decomposers play an essential role in nutrient cycling by breaking up plant litter and other detritus and returning it to a mineral form that can be utilized by plants (Hutson, 1980).

Levels of dehydrogenase and ATP on the WS were lower than on the FT but were much higher than on the US or the UH, which may lead to improved decomposition and mineralization of nutrients for root uptake. Dehydrogenase and ATP levels were positively correlated to tree growth (Table 7), suggesting that microbes may be increasing nutrient availability and forming symbiotic relationships with tree roots. WS had the most microbial biomass and activity of the three spoil materials, which were both positively correlated with tree growth. This may have been due to a combination of its lower pH and higher water retention, which is more conducive to microbial growth and activity.

Overall, physical properties had the greatest impact on tree growth. Current literature supports these conclusions. Bussler et al. (1984) found on reclaimed forestland in southwestern Indiana that, while chemical properties were similar or better on mine spoils compared to adjacent native soils, water holding capacity and rock fragments were much different. Rock fragments on the topsoil were around 1.53 g cm^{-3}, while they were 1.77 g cm^{-3} in the overburden. Also, water-holding capacity of the topsoil was 16.5% compared to spoil (10.8 to 11.7%). This suggests that soil physical properties are more important than chemical properties to tree growth on strip-mined sites. However, the similarities in chemical properties may also have resulted from the replacement of topsoil on these sites. Although pH and P, and perhaps N, are playing a role, water retention and coarse fragment content are more important to tree growth in this study.

Effect of Topsoil Inoculation

While topsoil inoculation had no effect on tree growth on the US or the WS, it did have a positive impact on tree growth on the UH. Topsoil inoculation affected many of the spoil properties, increasing or decreasing their levels to closer approximate the FT. Inoculation decreased the very high pH of the UH, which may have increased the availability of some nutrients, thereby increasing growth. The lower pH may have also improved the soil environment for the growth of a native soil fauna population (Wei-Chun Ma, 1989). The addition of topsoil may not have been as important on the WS because it already had a conducive environment for soil fauna and microbial growth. On the other hand, the US may have had such low water retention and high coarse fragments that, even though the addition of topsoil decreased pH and improved the material somewhat, other factors were limiting. The UH may have been a poor material for tree growth by itself, but had the potential for improved growth with a decrease in pH due to high nutrient content and high moisture retention, both of which would create a better environment for microbial growth.

In a study conducted in Alabama, Cross and colleagues (1987) found that after seven years replacement of topsoil on an alkaline Pottsville shale, *P. taeda* increased in height (4.68 m) and in diameter (7.34 cm) compared to sites where topsoil was not replaced (4.04 m and 6.30 cm, respectively). This shale was higher in pH (6.25) and coarse fragments (56.6%) than the topsoil (5.0 and 31.6%, respectively).

As mentioned above, Schoenholtz et al. (1992) found that topsoil addition increased total and mineralizable N levels by 23% and 46%, respectively, over the control after three years. Vegetation productivity, however, did not increase. Plants were more affected by water availability than by N availability on these plots. On the current study, physical properties may also have been more important, though N levels may affect tree nutrition over the long term.

In southwest Virginia, Moss and colleagues (1989) found that addition of 30 cm of mixed A, E, B, and C horizons on top of spoil did little to change soil properties and had no effect on survival or growth of planted pitch x loblolly pines (*P. rigida* Mill. x *P. taeda* L.). This manner of topsoil addition that includes the B and C horizons is much more realistic in the Appalachians because the A horizon can be thin in places. This suggests that the nutritional value of topsoil in the Appalachian region is still debatable. However, the spoil material that was used for Moss's study was already a 2:1 sandstone/siltstone mix, which had physical and chemical properties similar to the topsoil and may have been less impacted by topsoil addition compared to spoils such as US and GUS that were very different from native topsoil.

Growth of understory vegetation was significantly higher on the topsoil-inoculated pots compared to pots that were not inoculated. Although the difference among spoils was not significant, the trend suggests that it is not only topsoil inoculation that is important but also the material with which it is mixed. A greater number of native plants grew on the WS compared to the UH or US, showing that it is more hospitable overall to the establishment of understory vegetation. Farmer et al. (1982) found that native forest topsoil placed on mine spoils in southern Appalachia can produce substantial native vegetation. Native seed banks produced 1.9×10^6 shoots ha^{-1}, with a diversity of 134 taxa after one growing season, supporting the potential growth of topsoil seedbanks. Not only is this important in light of sprouting seeds from topsoil inoculation, but also for the establishment of seeds that may be transported to the area by wind or animals. Furthermore, inoculated pots had significantly higher microbial levels, further adding to the return of the native ecosystem. The return of microbial populations can lead to improvements in the establishment of the native forest by mineralization of nutrients, nitrogen fixation and symbiotic relationships with tree roots.

Although inoculation only improved growth on the UH, the added benefit of improved understory vegetation growth from the native seed bank and increased microbial growth suggests that inoculation with the native topsoil may be an important step in the reclamation process regardless of spoil type. Inoculation improves the potential for the return of understory vegetation and microbial populations, which comprise an important part of the diverse native hardwood ecosystem as a whole.

Species Differences

Not only was overall tree growth influenced by spoil type, but the three species displayed different growth responses to each spoil. *L. tulipifera* did not react well to any of the spoils and grew about the same on all treatments. Zeleznik and Skousen (1996) also found that *L. tulipifera* survival and growth was much poorer on strip-mined sites compared to other trees planted, with survival rates ranging from 3% to 21%. Planted *L. tulipifera* is highly sensitive to site quality, growing well on good sites and poorly on poor sites (Beck, 1990). All of the spoil materials would be considered poor soils comparatively due to their low organic matter, low nutrient levels and poor soil structure. The control soil came from a side slope, which is typically a poorer soil than that found on toeslopes or cove positions. *L. tulipifera* grows best on high-quality cove positions. Both nutrient levels and soil physical properties such as water availability and aeration have been correlated with growth of *L. tulipifera* and are important to its survival and growth (Beck, 1990). Beck (1990) reported that in the first few years of life, water availability and drainage are critical for the survival and good growth of *L. tulipifera.* Also, this tree is commonly propagated from stump sprouts or seeds in the forest floor, and is not often planted as seedlings (Beck, 1990).

F. americana and *Q. rubra* showed clear but somewhat different responses to spoil type. *F. americana* had the greatest growth response and displayed different growth rates on each spoil. Next to the FT, the WS was the best medium for *F. americana* growth, based on both root and stem biomass. *Q. rubra* was more successful on the WS than any other medium, including the FT.

Among the three species, *F. americana* was the most successful on all spoils. This suggests that it was most able to adapt to the highly variable properties of these different materials. In eastern Ohio, Zeleznik and Skousen (1996) found that *F. americana* was the most successful species planted compared to *L. tulipifera* and *P. strobus*. After 46 years, *F. americana* had a survival rate of 43% and was doing equally well on spoils that ranged in physical properties. In central Ohio, Kost et al. (1998) found that among six species, *F. pennsylvanica* had the best survival rate (95%), with the next highest being *P. nigra* at 60%, on alkaline spoils covered with acid topsoil after nine years. This supports our findings that *Fraxinus* is able to survive and grow well on spoils when other trees are not. Whether this is due to its ability to tap nutrient pools or if it has greater tolerance to other limiting spoil properties is still debatable.

Torbert et al. (1985) found on a reclaimed site in Virginia that *F. americana* had a survival rate of 91% and a growth rate of 24 cm on herbicide-sprayed plots after 3 years. In contrast, *L.*

tulipifera had survival rates of 54% and height growth of only 11 cm. Interestingly, *Q. rubra* did not fare well on their experiment, with a survival rate of 43% and growth of only 6 cm. In this study, *Q. rubra* growth was intermediate, not as vigorous as the *F. americana*, but growing adequately on all spoil types.

Conclusions

The return of the diverse mixed mesophytic forest of the Appalachian Mountains on reclaimed strip mine sites may be greatly influenced by spoil type. This research shows that the growth of two of the three native hardwood species used in this study are affected by the physical, chemical, and biological properties of mine spoils. Spoils that were approximately equal to the natural soils of the region, such as WS (weathered sandstone) were more conducive to native hardwood growth than the US (unweathered sandstone) or UH (unweathered shale). This was due to the low percentage of coarse fragments, higher water retention, and lower pH. Nutrient availability may have also played a role.

The inoculation with native topsoil improved tree growth on the UH, added a native seed pool, and increased microbial populations, suggesting that the addition of native topsoil to spoils could speed up the return of the native mixed mesophytic forest by creating an environment rich in native microbes and seeds.

Our study shows that some species are much more adept at growing on reclaimed sites and that the timely return of the diverse forest that was there prior to mining requires spoil selection and treatment. While *F. americana* may have grown well, species that are more sensitive to site quality, such as *L. tulipifera,* may need good quality sites or different stock type in order to establish and grow well.

Overall, this study showed that spoil selection, return of topsoil, and species selection to match soil characteristics are all important factors to consider during the reclamation process. In order to best establish the native mixed mesophytic forest, weathered sandstone was found to be the best topsoil substitute tested in this study. The benefits of topsoil were biological as native plants were introduced in the seed pool and soil microbial biomass and activity were greater; however, it has little direct effect on spoil fertility. Many of the mid- to late-successional native hardwoods with life histories similar to ash and red oak can be expected to grow well on WS spoil amended with topsoil.

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