Mine soil suitability for native forests in the USA

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Abstract
Northern red oak is a valuable, native commercial species in large areas of the eastern USA. Little is known about preferred site and soil conditions for this species on mined land. The purpose of our field study was to test red oak survival and growth rates on a variety of topsoil substitutes. The site was mined in 1979 and reclaimed in 1980. In 1981, field plots were constructed with different topsoil substitutes spoil mixes and pitch x loblolly pines were planted in 1983. In 2001 the pines were removed and replaced with red oaks in the winter of 2001-2002. Four replicate plots of five different mine spoil mixes were planted with nine red oak seedlings each. Tree survival, height and diameter were measured each year for five years. Survival and growth was best on topsoil substitutes consisting of a mix of sandstone and siltstone. Trees survived and grew poorly on plots constructed from either pure sandstone or siltstone. Reasons for the poor oak performance on the high sandstone plots were related to lower pH and available Ca levels. Poor oak performance on the pure siltstone plots was likely related to higher rock fragment and lower bulk water holding content.

Key Words
Reclamation, coal mined land, forest management, soil quality, mine soils.

Introduction
The Appalachian coalfields region is heavily forested with native temperate hardwoods. The forest has been a major economic resource since the region was settled by Europeans more than 200 years ago. In addition to wood products, the forest provides ecosystem services including watershed protection, water quality, carbon sequestration, wildlife habitat, and habitat for many understory plants and animals used for food and sustenance by local communities (Braun 1950). Since the implementation of the Surface Mining Control and Reclamation Act (SMCRA) in 1978, most reclaimed mines were re-vegetated with grasses and other herbaceous plants. Because there is no significant livestock industry in the steeper mountains, and because these new grasslands are usually remote, at high elevation, and with little water, the grassland created on mined land is usually abandoned to become low-value scrubland. Restoring adequate mine soil quality for trees using suitable topsoil substitutes has been an on-going issue (Bussler *et al.* 1984, Rodrigue and Burger 2004). In 1983 we planted pines in different mixtures of sandstone and siltstone overburdens on a study site in Wise County, Virginia. The site had been a native hardwood forest on steep terrain prior to mining, and after mining it was relatively level and was surrounded by a variety of post-mining land uses ranging from pasture to pine plantations. Pines grew best in mine soils with a high proportion of lower pH sandstone spoil despite overall lower fertility compared to that in the siltstone spoil (Torbert *et al.* 1990). This led to a recommendation that weathered, slightly acid sandstone spoils be used for topsoil substitutes for forestry post-mining land uses. However, with increasing interest in commercially valuable native hardwoods, we revisited the issue to determine which mine soil types are most suitable for these more demanding hardwood species.

The objective of this research was to determine the suitability of different topsoil substitutes for northern red oak (*Quercus rubra* L.) after removing pines that had been planted in the same area immediately after reclamation and had been in place for 19 years. The topsoil substitutes were made up of different proportions of sandstone and siltstone overburden. Red oak was chosen as an indicator species because of its commercial value, its sensitivity to mine soil conditions, and the fact that it shares many resource requirements with other native hardwood species (Johnson *et al.* 2002).

Methods
The study site is located in Wise County, Virginia. The study plots were constructed during the winter of 1981 on a previously mined flat bench. The area around the site was mined in 1983, which left the surrounding terrain relatively flat. The treatment plots consisted of four replications of five overburden mixes that included pure sandstone (SS), pure siltstone (SiS), 2:1 SS:SiS, 1:1 SS:SiS, and 1:2 SS:SiS arranged in a

randomized complete block design. The spoils were mixed in the required ratios and placed in the centers of adjacent 3.05 x 6.1 x 1.25 m deep plots. In the spring of 1983, each plot was planted with nine containerized 1-0 pitch x loblolly pine hybrid (*Pinus rigida* Mill. x *Pinus taeda* L.) seedlings. Tree survival, height, and ground line diameter of the stem were measured in the fall of each year for the 5-yr study period. The results of the study were reported by Torbert *et al.* (1990).

Trees were removed in 2001, and in 2002 each of the 20 plots was replanted with nine 2-0 northern red oak seedlings. Survival, height, and ground line diameter of the trees were measured in the fall each year for five years. At the end of the fifth field growing season for both the pines (1987 and the oaks (2006), two 1-kg soil samples were taken from each plot and combined for a single composite sample. Soil physical and chemical properties were determined using standard methods. Data were summarized and analyzed using ANOVA and regression statistics (SAS 2004).

Results and Discussion

Pine growth was greatly affected by overburden type. Tree volume in the study plots decreased proportionately with added siltstone (Torbert *et al.* 1990) (Figure 1). Torbert and co-workers attributed the decrease in tree production to a combination of physical and chemical properties, namely coarse fragment content, pH, and higher initial soluble salt content, all of which increased with increasing amounts of siltstone (Figure 2). Pine growth was inversely proportional to soluble salt content; growth decreased linearly as salt content increased (Figure 2). Soluble salt content ranged from 1280 to 4160 mg/kg 1987 with increasing amounts of siltstone in the first five years of the experiment. In contrast to the pines, the northern red oaks grew best in topsoil substitutes consisting of 1:1 SS:SiS and 1:2 SS:SiS (Figure 1, Table 1). Average tree height on the 1:2 SS:SiS sandstone:siltstone mixture was greater than the average tree height on either of the pure rock types. The trends in ground line diameter, tree volume index (TVI = diameter^2 x height), and plot volume index (TVI x % survival / 100) were the same as that for tree height (Table 1). Tree survival was very close to 70% at age 5 for all treatments except for the pure sandstone, which was only 25%. Seventy percent survival is common and considered good for mixed native hardwoods planted in good mine soils.

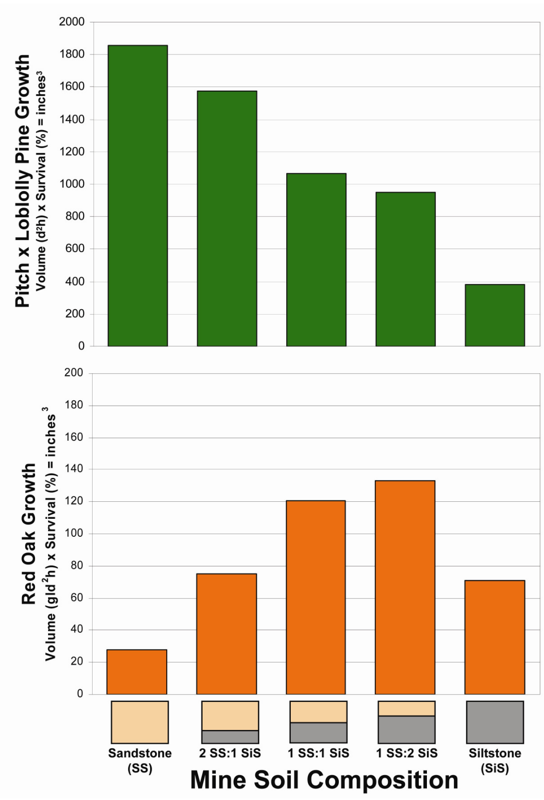

Figure 1. Pine and red oak production in topsoil substitutes consisting of different amounts of sandstone and siltstone. Tree growth is shown as an estimate of biomass volume x survival (ground line d^{2}h x % survival/100) (Pine data from Torbert *et al.* 1990).

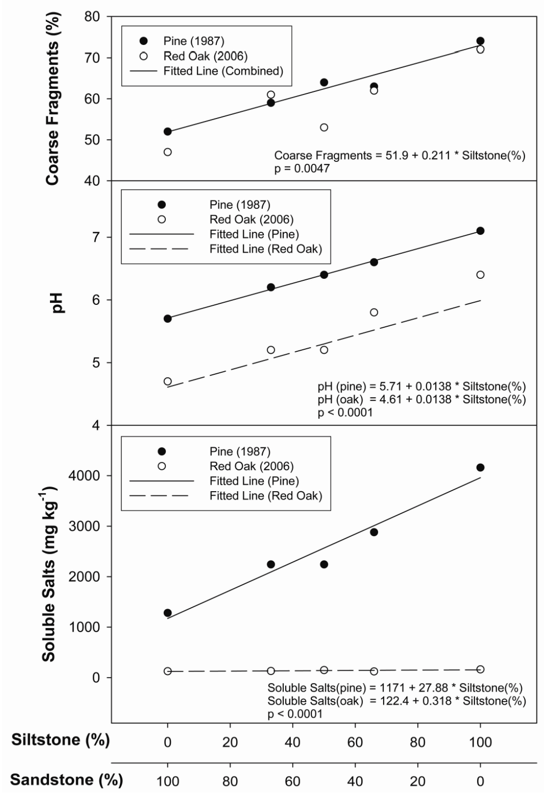

Figure 2. Coarse fragment content, pH, and soluble salt content for increasing amounts of siltstone versus sandstone used as a topsoil substitute for growing pitch x loblolly pines (1983-1987) (Torbert *et al.* 1990) followed by northern red oaks (2002-2006).

By 2002, when the red oaks were planted, the mine soils had been in place and weathering for 20 years. Furthermore, the mine soils had been exposed to the influences of a pine cover for 19 years. When the soils were sampled in 2006, they had been in place for 25 years. Therefore, differences in soil properties between sampling periods (1987 and 2006) are largely a function of parent material (sandstone versus siltstone), but would also be a function of time and vegetation (pines and northern red oak).

Total N and C, averaging 0.2 and 3%, respectively, were comparable to levels found in non-mined, managed forest soils of the southeastern United States (Fisher and Binkley 2000) (Table 3). The only soil property that appeared correlated with tree growth was the soil CEC corrected for fine earth content (Table 2). The CEC was lowest for the pure rock types and highest for the mixtures, which corresponded to red oak growth. An overall CEC of only 2.0 $cmol^+$ /kg is an indication of potentially low soil fertility by agricultural standards, but this level is common in moderately to strongly acid native forest soils (Fisher and Binkley 2000). Of the soil properties measured for this study, low soil P and high coarse fragment content are possible factors contributing to the poor red oak growth on the pure siltstone (Showalter *et al.* 2005).

Based on these data, the red oaks survived and grew poorly on the sandstone mine soil. This soil had the highest levels of available N and P, which were comparable to or higher than those found on an adjacent sandstone study site growing healthy 15-year-old sugar maples (Burger and Salzberg, in press). However, the sandstone pH in this study (4.7) was one unit lower than that on the sugar maple site (5.7). A combination of strong acidity and the lowest levels of exchangeable bases were possible causes of the poor performance on sandstone.

Table 1. Survival and growth of planted northern red oaks growing on sandstone and siltstone topsoil substitutes.

	Survival		Growth (age 5)			
	Year 1	Year 5	Diameter[1]	Height	TVI[2]	PVI[3]
	(-------- % --------)		(cm)	(cm)	(cm^3)	
Sandstone	64	25^b	2.8	116^b	1822	456
2:1 SS:SiS	78	69^a	3.1	146^{ab}	1777	1226
1:1 SS:SiS	75	69^a	3.1	151^{ab}	2869	1980
1:2 SS:SiS	83	72^a	3.7	174^a	3026	3179
Siltstone	75	69^a	3.0	122^b	1696	1170

[1]Diameter at ground line.
[2]Mean Tree Volume Index = (ground line diameter)^2 x (height)
[3]Plot Volume Index = (TVI)(% survival) / 100

Table 2. Selected physical and chemical properties for sandstone and siltstone topsoil substitutes under red oak.

Mine Soil	Fine Earth	pH	Soluble Salts	Olsen[1] P	Inorganic[1] N (KCl)	CEC[2] (x FE)
	(%)		(ppm)	------- kg/ha -------		($cmol^+$ /kg)
Sandstone	53^a	4.7^d	125	24.5	35.0	1.85
2:1 SS:SiS	39^b	5.2^c	131	11.5	27.1	2.02
1:1 SS:SiS	47^{ab}	5.2^c	150	16.7	35.1	2.26
1:2 SS:SiS	38^{bc}	5.9^b	122	9.0	18.6	2.20
Siltstone	28^c	6.4^a	163	7.7	13.1	1.60

[1]kg/ha values based on D_b = 1.3 g/cm^3 and soil layer = 0-20 cm (Olsen and Sommers 1982).
[2]CEC x fine earth (FE) fraction

Table 3. Total nitrogen and carbon and exchangeable cations for sandstone and siltstone topsoil substitutes under red oak.

Mine Soil	Total N[1]		Total C[1]		Exchangeable Cations[2]			
					Ca	K	Mg	Na
	(%)	(kg/ha)	(%)	(Mg/ha)	---------- ($cmol^+$ /kg) ----------			
Sandstone	0.16	2204	2.91	40.0	2.43	0.05^b	1.01^d	0.05
2:1 SS:SiS	0.18	1920	3.55	37.6	3.11	0.07^a	1.98^{bc}	0.06
1:1 SS:SiS	0.19	2368	3.50	43.7	2.82	0.08^a	1.88^c	0.07
1:2 SS:SiS	0.17	1713	3.32	32.2	3.37	0.08^a	2.29^b	0.05
Siltstone	0.22	1519	4.34	30.2	2.76	0.08^a	2.88^a	0.05

[1]kg/ha values based on D_b = 1.3 g/cm^3 and soil layer = 0-20 cm.
[2]Ammonium acetate extracts.

Conclusion

In contrast to the pitch x loblolly pines, which preceded the northern red oaks on the same study plots, red oaks clearly grew best in a mix of sandstone and siltstone. They survived well on all the mine soils except pure sandstone, but grew poorly on both pure sandstone and pure siltstone. This difference in growth between the two species may show a species preference for different mine soils; however, the reason for this preference could not be attributed to a single mine soil property. Northern red oaks, along with most other native hardwoods, are known to have a higher base nutrient requirement than pines, which may explain their better performance in the mixtures of the two rock types, while low soil P, high coarse fragment content, and low water availability may have slowed their growth in the pure siltstone. In any case, these results show that trees respond very differently to different mine soils, and they show that mine soils suitable for tree survival and growth should be used to restore forest productivity.

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