RED OAK SEEDLING RESPONSE TO DIFFERENT TOPSOIL SUBSTITUTES AFTER FIVE YEARS[1]

James A. Burger, David Mitchem, and W. Lee Daniels[2]

Abstract: Northern red oak is a valuable commercial species occurring throughout the Appalachian Coalfields Region. It reportedly grows on mined land, but 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 study is located in Wise Co., Virginia on the Marcum Hollow member of the Upper Wise Formation. 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. Mine spoils consisted of different proportions of weathered sandstone and un-weathered siltstone. Tree survival, height and diameter were measured each year for five years. Results show that 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 not clear, but could possibly be related to lower pH and available Ca levels. Poor oak performance on the pure siltstone plots was most likely related to higher rock fragment and lower bulk water holding content.

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

---

[1] Paper was presented at the 2007 National Meeting of the American Society of Mining and Reclamation, Gillette, WY, 30 Years of SMCRA and Beyond June 2-7, 2007. R.I. Barnhisel (Ed.) Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

[2] James A. Burger is Professor and David Mitchem is Senior Laboratory Specialist, Department of Forestry, and W. Lee Daniels is Professor of Soil Science, Department of Crop and Soil Environmental Sciences, at Virginia Polytechnic Institute and State University, Blacksburg, VA 24061.

Proceedings America Society of Mining and Reclamation, 2007 pp 132-142
DOI: 10.21000/JASMR07010132

http://dx.doi.org/10.21000/JASMR07010132

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.

During the past decade, however, landowners have become increasingly interested in reforesting mined land with native tree species to create long-term economic value on their reclaimed land. At the request of landowners, some coal operators have been planting native hardwoods, but with mixed success. Most coal operators used the same grassland reclamation procedures they used in the past and simply planted trees as an additional step in the reclamation process. Poor tree survival was common, and when trees did survive, they grew poorly. Research has since shown that this poor tree performance was due to unsuitable mine soils, compacted surfaces, and the use of competitive agricultural grasses and legumes for erosion control ground covers (Burger et al., 2002).

Beginning in the early 1980s, researchers at Virginia Tech began developing reclamation procedures that increased tree survival and restored land productivity to levels that existed prior to mining (Torbert et al., 1985; Burger and Torbert, 1992; Burger et al., 1998). The effects of mine soil selection (Torbert et al., 1988), mine soil compaction (Torbert and Burger, 1996), and tree-compatible ground cover (Torbert et al., 1995) on tree survival and growth were studied and documented. Research findings were used to develop preliminary regional reclamation guidelines for reforestation (Burger and Zipper, 2002).

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 (Fig. 1). The overburden was obtained from an adjacent mining operation on the Taggart and Taggart Marker coal seams of the Marcum Hollow member of the Upper Wise Formation. The spoils were mixed in the required ratios and placed in the centers of adjacent 3.05 x 6.1 m (10 x 20 ft) plots. Piles were graded flat with a small (D-4 Caterpillar) dozer, taking care to reduce compaction. The final loose spoil depth was 1.24 m over the compacted underlying bench. In the spring of 1983, half of each plot was planted with nine containerized 1-0 pitch x loblolly pine hybrid (*Pinus rigida* Mill. x *Pinus taeda* L.) seedlings; the other half of each plot was sown to fescue for forage studies. 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).

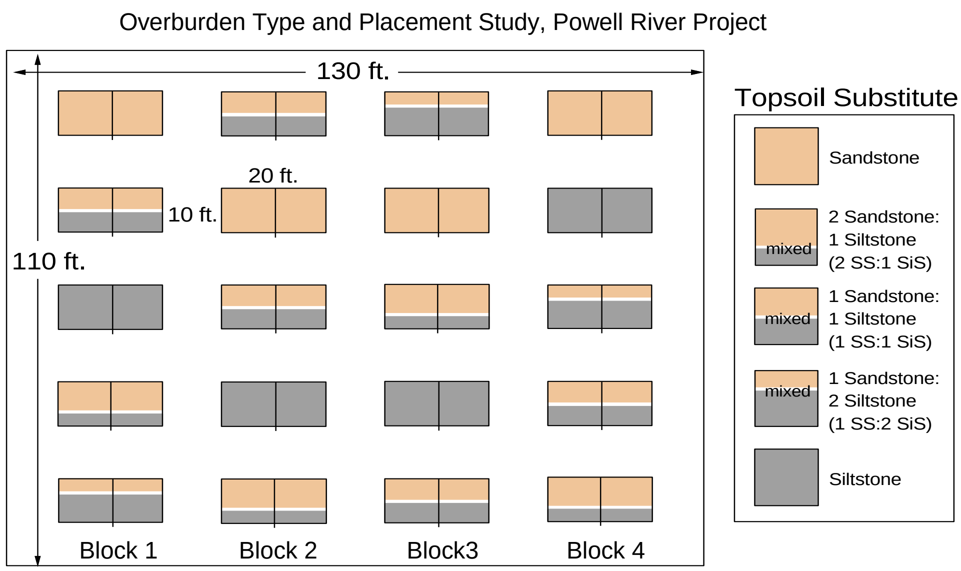

Figure 1. Plot layout for the overburden type and placement study showing the different amounts of sandstone and siltstone that made up the topsoil substitutes. Mixtures were blended prior to placement. Plots were 3.05 x 6.10 m in size, and were split with trees and tall fescue in each plot half.

During 1998-99, southern pine beetles (*Dendroctonus frontalis* Zimmermann) infested the trees. 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. Soils were sieved to separate coarse fragments from the fine-earth fraction (< 2 mm). Soil pH was determined in a 2:1 soil:water suspension with a glass electrode (McLean, 1982), and soluble salts were determined in a 2:1 suspension using procedures described by Bower and Wilcox (1965). Exchangeable Ca, Mg, K, and Na were extracted using a 1 M NH_4Ac solution (Thomas, 1982) and analyzed using an ICP spectrophotometer (SpectroFlame Modula Tabletop ICP, Spectroanalytical Instruments Inc., Fitchburg, MA). Ammonium and NO_3 were extracted using a 1 M KCl solution (Bremner 1965). Total N and C were measured using a carbon-nitrogen analyzer (Vario MAX, Elementar MAX Instruction Manual 2000). Available nutrients were estimated using the Mehlich I extraction, and available P was measured using the sodium bicarbonate method (Olsen and Sommers, 1982). 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) (Fig. 2). 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 (Fig. 3). As coarse fragment content increases, there is less fine earth for trees to exploit for water and nutrient resources; therefore, the disadvantage of high coarse fragment content is largely a function of accessible soil volume.

The pH of native Appalachian forest surface soils commonly ranges between 4.5 and 5.5, but some native hardwood species, including the oaks, can tolerate pH levels between 4.0 and 7.0. Native southern pines, including pitch and loblolly, are especially adapted to acid soils and are less tolerant of pH levels that exceed 6.5. Pine growth was inversely proportional to pH; growth decreased linearly as pH increased through a range of 5.7 to 7.1 (Fig. 3). It is unlikely that this was a cause and effect relationship. Trees are seldom directly affected by the H^+ concentration within this range (Fisher and Binkley, 2000); instead, they would be affected by secondary chemical and biological factors caused by soil pH.

Pine growth was also inversely proportional to soluble salt content; growth decreased linearly as salt content increased (Fig. 3). Soluble salt content ranged from 1280 to 4160 mg kg^{-1} 1987 with increasing amounts of siltstone in the first five years of the experiment. It is likely that this was a cause and effect relationship based on a number of studies that documented the salt sensitivity of pines and Appalachian hardwoods. High levels of soluble salts inhibit water and carbon dioxide uptake, and also inactivate enzymes affecting protein synthesis, carbon metabolism, and photophosphorylation (Taiz and Zeigler, 1991). Rodrigue and Burger (2004) found a significant relationship between white oak site index and soluble salt content for a collection of 14 20- to 60-year-old stands on mined land. Soluble salt levels ranged from 100 to 1000 mg kg^{-1} compared to a range of 128 to 278 mg kg^{-1} for eight non-mined, mature, native hardwood forests. McFee et al. (1981) listed soluble salts as one of the most influential soil properties on Indiana mine soils, especially when levels exceeded 1300 mg kg^{-1}. Torbert et al. (1988) also suggested that levels above 1000 mg kg^{-1} could affect tree survival and growth. According to the Soil and Plant Analysis Council (1992), 1000 mg kg^{-1} is considered "moderately saline," where seedlings may be injured and yields of salt-sensitive crops are restricted. Based on these research findings, it is reasonable to consider 1000 mg kg^{-1} a limit that should be avoided.

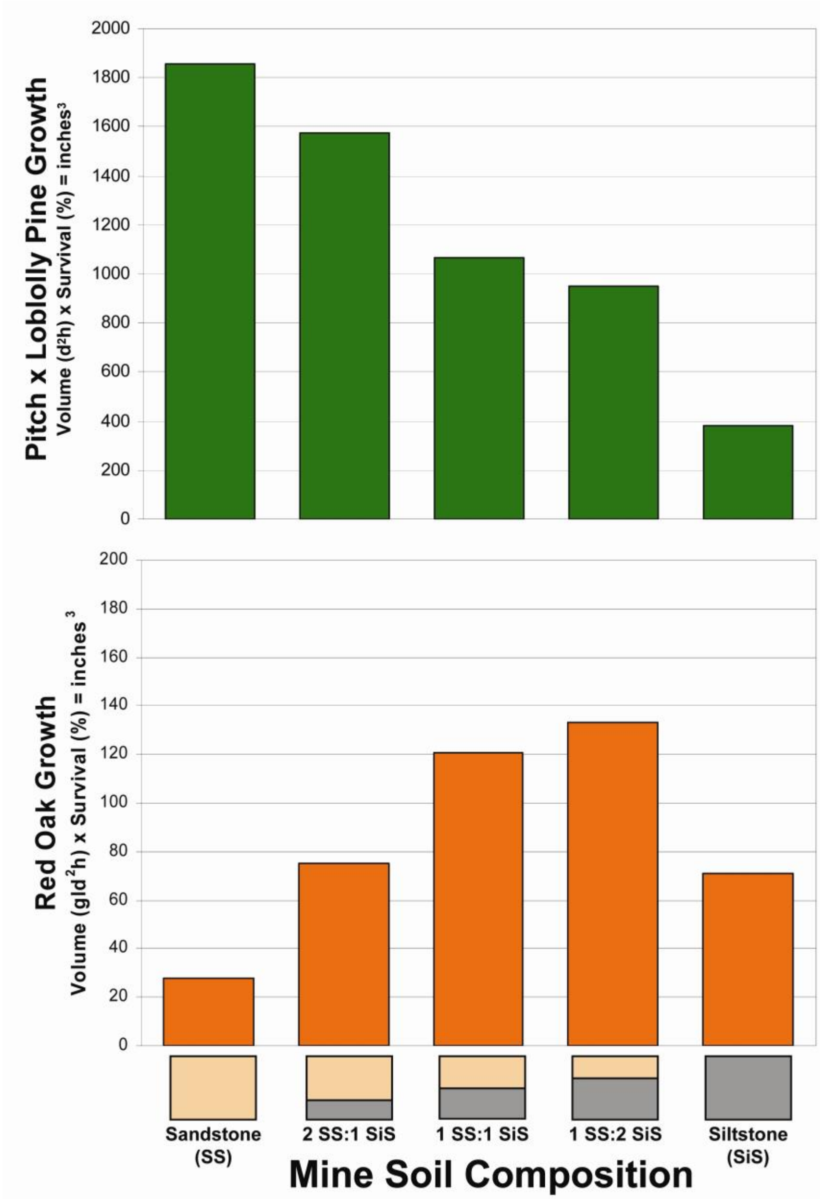

Figure 2. Pine and red oak production in topsoil substitutes consisting of different amounts of sandstone and siltstone. Tree growth is shown as an estimate of biomass volume x survival (ground line d^2h x % survival/100) (The pine data are from Torbert et al., 1990).

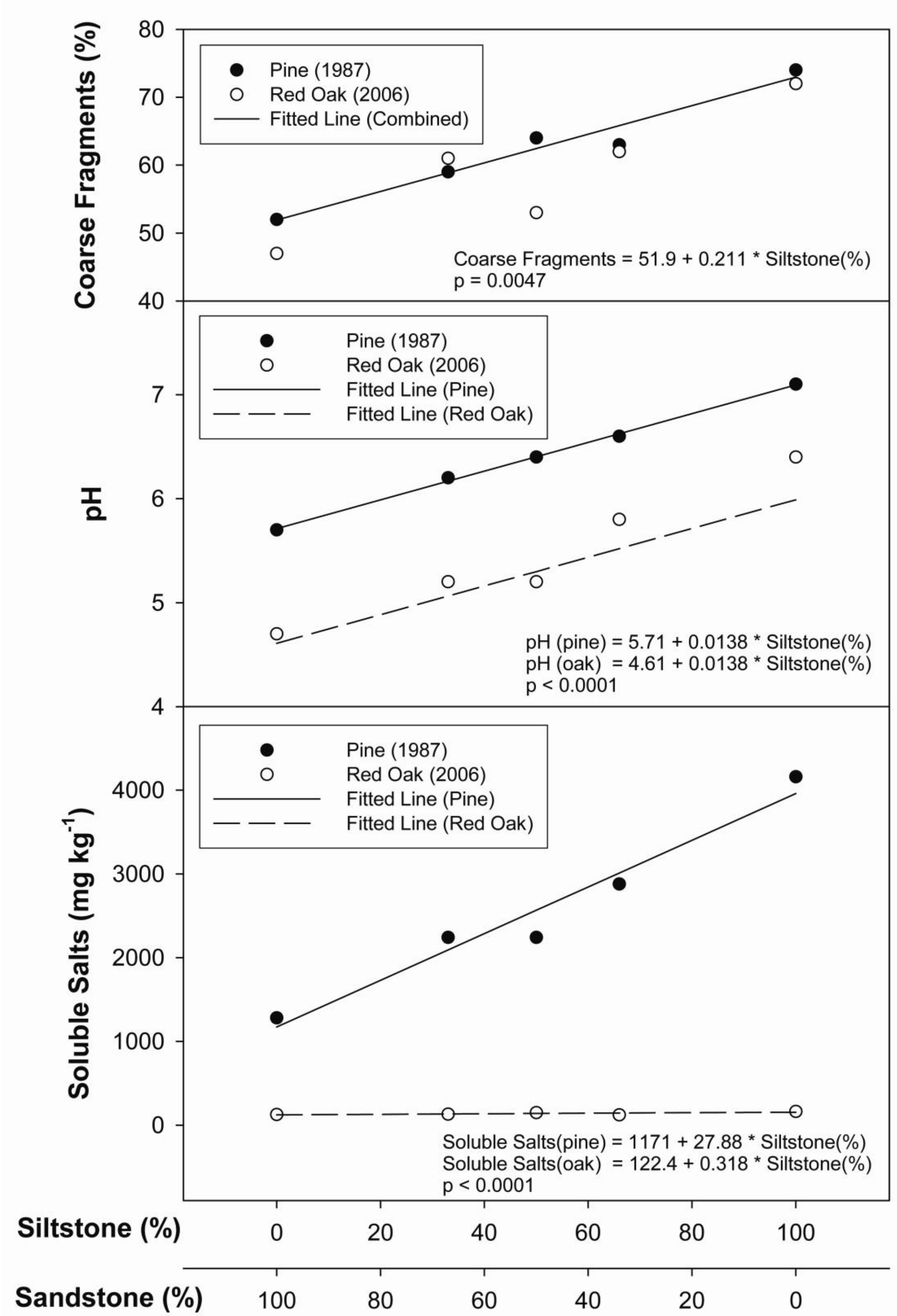

Figure 3. Coarse fragment content, pH, and soluble salt content for increasing amounts of siltstone versus sandstone used as a topsoil substitute for growing pitch x loblolly pines (1983-1987) (Torbert et al., 1990) followed by northern red oaks (2002-2006).

Whole soil water retention (1500-33 kPa) was 43 versus 24 g kg^{-1} in the sandstone and siltstone spoils, respectively, which could also have played a role (Torbert et al., 1990). Foliar analyses showed that the pines were adequately nourished with all essential elements. One micronutrient, foliar Mn, was 540 and 160 mg kg^{-1} for the sandstone and siltstone mine soils, respectively. Levels between 300 to 400 mg kg^{-1} are considered sufficient (Stone, 1968); therefore, Mn is one nutrient element that may have played a role in the pines' slower growth in plots with increasing amounts of siltstone spoil (Torbert et al., 1990).

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 (Fig. 2; 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 (R. Williams, personal communication).

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 = $(\text{ground line diameter})^2$ x (height)
[3] Plot Volume Index = (TVI)(% survival) / 100

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). Coarse fragment content changed little during the sampling interval (Fig. 3). A regression analysis using the two sampling periods as a dummy variable showed no significant breakdown of the coarse fragments during this 20-year period. Coarse fragment content ranged from about 50% in the sandstone to 75% in the siltstone, with intermediate amounts roughly proportional to the SS:SiS ratio. Soil reaction decreased approximately one pH unit across all treatments over the soil sampling interval (the line intercepts were different, but the slopes were not). Soluble salt content dropped dramatically (Fig. 3), showed no rock mix effect in 2006 (both the line intercepts and slopes were different), and fell within the range for native forest soils (128-278 mg kg^{-1}) reported by Rodrigue and

Burger (2004). This undoubtedly reflects the long term leaching loss of the initial soluble salt component of the SiS which was deleterious to the pines in the first five years.

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 trend was for both total N and C concentration to increase as siltstone content increased; however, total content in the surface 20 cm (kg ha^{-1}) was greater in the sandstone mine soil due to its greater proportion of fine earth. Available P and N generally decreased with increasing siltstone (Table 2). The levels of KCl-extractable inorganic N and Mehlich I-extractable nutrients all appeared to be adequate for normal tree growth. However, P levels using the Olsen extraction, which is a better indicator of available P in soils with a near-neutral reaction, appeared to be deficient compared to recommended levels of 15 kg ha^{-1} for normal growth of most plants (Thomas and Peaslee, 1973). Mehlich I-extractable soil K and Fe content (kg ha^{-1}) in the surface 20 cm decreased with increasing siltstone, while Ca and Mg increased (Table 4). 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^{-1} 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).

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

Mine Soil	Fine Earth (%)	pH	Soluble Salts (ppm)	Olsen[1] P (------- kg ha^{-1} -------)	Inorganic[1] N (KCl) (------- kg ha^{-1} -------)	CEC[2] (x FE) ($cmol^{+}$ kg^{-1})
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^{-1} values based on D_b = 1.3 g cm^{-3} and soil layer = 0-20 cm.
[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.

	Total N[1]		Total C[1]		Exchangeable Cations[2]			
					Ca	K	Mg	Na
Mine Soil	(%)	(kg ha^{-1})	(%)	(Mg ha^{-1})	---------- (cmol^{+} kg^{-1}) ----------			
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^{-1} values based on D_b = 1.3 g cm^{-3} and soil layer = 0-20 cm.
[2] Ammonium acetate extracts.

Table 4. Mehlich I-extractable nutrients for sandstone and siltstone topsoil substitutes under red oak.

	P	K	Ca	Mg	Mn	Fe
	------------------------- (mg kg^{-1}) -------------------------					
Sandstone	19^{c}	34	531^{d}	110^{c}	57^{a}	91^{a}
2:1 SS:SiS	22^{c}	41	736^{c}	201^{b}	43^{b}	86^{ab}
1:1 SS:SiS	26^{c}	36	770^{c}	189^{b}	49^{ab}	83^{ab}
1:2 SS:SiS	34^{b}	38	956^{b}	229^{b}	45^{b}	71^{bc}
Siltstone	47^{a}	42	1437^{a}	336^{a}	59^{a}	60^{c}
	------------------------- (kg ha^{-1})[1] -------------------------					
Sandstone	26	46	721^{c}	149^{b}	79^{a}	68^{a}
2:1 SS:SiS	22	42	751^{bc}	204^{a}	45^{b}	48^{bc}
1:1 SS:SiS	31	43	938^{ab}	226^{a}	61^{ab}	55^{ab}
1:2 SS:SiS	33	38	935^{ab}	224^{a}	46^{b}	38^{cd}
Siltstone	34	30	1025^{a}	242^{a}	43^{b}	24^{d}

[1] kg ha^{-1} values based on D_b = 1.3 g cm^{-3} and soil layer = 0-20 cm.
[2] CEC x fine earth fraction

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 extractable and exchangeable bases were possible causes, although red oak is known to grow relatively well in strongly acid, base-depleted soils (Hicks, 1998).

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. By the time the red oaks were planted, the mine soils had weathered for about 20 years. The pH and soluble salt content dropped considerably, so we can only speculate how they might have grown under the conditions the pines experienced. 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.

Acknowledgments

We greatly appreciate the assistance and support from the Powell River Project, and early financial support form the Office of Surface Mining. And many thanks go to Kathryn Hollandsworth and Dr. Mark Eisenbies for their technical assistance.

Literature Cited

Bower, C.A., and L.V. Wilcox. 1965. Soluble salts. P. 933-951. *In:* Methods of soil analysis, Pt. 2. C.A. Black (ed.). Amer. Soc. Agron. Pub. No. 9.

Braun, E. L. 1950. Deciduous forests of Eastern North America. Garden City, New York, The Blakiston Co. 596p.

Bremner, J.M. 1965a. Inorganic forms of nitrogen. p. 1179-1237. *In:* Methods of soil analysis, Pt. 2. Black, C.A. (ed.). Amer. Soc. Agron. Pub. No. 9.

Burger, J.A., and J.L. Torbert. 1992. Restoring forests on surfaced-mined land. Virginia Coop. Exten. Publ. No. 460-123. Blacksburg, VA. 16 p.

Burger, J.A, D.L. Kelting, and C.E. Zipper. 1998. Maximizing the value of forests on mined land. Virginia Coop. Exten. Publ. 460-138. Blacksburg, VA. 8 p.

Burger, J.A., and A. Salzberg. 2007. Sugar maple response to weed control, liming and fertilization on a reclaimed mine soil in southwestern Virginia. N. J. Appl. For. (in press).

Burger, J.A., and C.E. Zipper. 2002. How to restore forests on surface-mined land. Powell River Project, Virginia Coop. Exten. Tech. Rep. 21p.

Burger, J.A., D.A. Scott and D.O. Mitchem. 2002. Field assessment of mine site quality for establishing hardwoods in the Appalachians. Proceedings America Society of Mining and Reclamation, 2002 pp 226-240. http://dx.doi.org/10.21000/JASMR02010226

Bussler, B.H., W.R. Byrnes, P.E. Pope and W.R. Chaney. 1984. Properties of minesoil reclaimed for forest use. Soil Sci. Soc. Am. J. 48:178-184. http://dx.doi.org/10.2136/sssaj1984.03615995004800010033x.

Fisher, R. F., and D. Binkley. 2000. Ecology and management of forest soils. New York: John Wiley and Sons. 489 p.

Hicks, Ray R. Ecology and management of central hardwood forest. 1998. New York: John Wiley and Sons. 432 p.

Johnson, P.S., S.R. Shifley and R. Rodgers. 2002. The ecology and silviculture of oaks. CABI Publ., New York. 503 p. http://dx.doi.org/10.1079/9780851995700.0000.

McLean, E.O. 1982. Soil pH and lime requirement. p. 199-224. *In:* A.L. Page et al. (ed.). Methods of soil analysis. Pt 2. 2nd ed. Agron. Monogr. No. 9. ASA and SSSA, Madison, WI.

McFee, W.W., W.R. Byrnes and J.G. Stockton. 1981. Characteristics of coal mine overburden important to plant growth. J. Environ. Qual. 10(3):300-308. http://dx.doi.org/10.2134/jeq1981.00472425001000030009x

Olsen, S.R., and L.E. Sommers. 1982. Phosphorus. p. 403-430. *In:* Methods of soil analysis, Pt. 2. Chemical and microbial properties. 2nd ed. Page, A.L., et al. (eds.). Amer. Soc. Agron. Pub. No. 9.

Rodrigue, J.A., and J.A. Burger. 2004. Forest soil productivity of mined land in the midwestern and eastern coalfield regions. Soil Sci. Soc. Amer. J. 68:1-11. http://dx.doi.org/10.2136/sssaj2004.8330.

SAS Institute. 2004. SAS System for Windows V8. SAS Institute Inc., Cary, NC.

Showalter, J.M., J.A. Burger, C.E. Zipper and J.M. Galbraith. 2005,Influence of physical, chemical, and biological mine soil properties on white oak seedling growth, Proceedings America Society of Mining and Reclamation, 2005 pp 1029-1041 http://dx.doi.org/10.21000/JASMR05011029

Soil and Plant Analysis Council, Inc. 1992. Handbook on reference methods for soil analysis. 202p.

Stone, E.L. 1968. Micronutrient nutrition of forest trees: A review. p. 132-175. *In:* Forest fertilization – theory and practice. Tennessee Valley Auth., Knoxville, TN.

Taiz, L., and E. Zeiger. 1991. Stress physiology. P. 362-364. *In:* Plant physiology. The Benjamin/Cummings Publ. Co., CA.

Thomas, G.W. 1982. Exchangable cations. P. 160-161. *In:* Methods of soil analysis, Pt. 2. Chemical and microbial properties. 2nd ed. Page, A.L. et al. (eds.). Amer. Soc. Agron. Pub. No. 9.

Thomas, G.W., and D.E. Peaslee. 1973. Testing soils for phosphorus. P. 115-132. *In:* L.M. Walsh and J.D. Beaton (ed.). Soil Testing and Plant Analysis. Soil Sci. Soc. of Amer., Inc., Madison, WI.

Torbert, J.L., J.A. Burger, J.N. Lien and S.H. Schoenholtz. 1985. Results of a tree species trial on a re-contoured surface mine in southwestern Virginia. S. J. Appl. For. 9(3):150-153.

Torbert, J.L., A.R. Tuladhar, J.A. Burger and J.C. Bell. 1988. Minesoil property effects on the height of ten-year-old white pine. J. Environ. Qual. 17(2):189-192. http://dx.doi.org/10.2134/jeq1988.00472425001700020004x.

Torbert, J.L., J.A. Burger and T. Probert. 1995. Evaluation of techniques to improve white pine establishment on an Appalachian minesoil. J. of Environ. Qual. 24: 869-873. http://dx.doi.org/10.2134/jeq1995.00472425002400050012x.

Torbert, J.L., J.A. Burger and T. Probert. 1995. Evaluation of techniques to improve white pine establishment on an Appalachian minesoil. J. of Environ. Qual. 24: 869-873. http://dx.doi.org/10.2134/jeq1995.00472425002400050012x.

Torbert, J.L., and J.A. Burger. 1996. Influence of grading intensity on herbaceous ground cover, erosion, and tree establishment in the southern Appalachians. Conf. Proc., Successes and failures: Applying research results to insure reclamation success, Knoxville, TN.