CAPABILITY OF RECLAIMED MINED LAND FOR SUPPORTING REFORESTATION WITH SEVEN APPALACHIAN HARDWOOD SPECIES[1]

James A. Burger,[2] and A. G. Fannon

Abstract. Reforestation of the Appalachian coalfields with native hardwoods is becoming increasing popular. However, establishing some hardwood species has been difficult due to the poor quality of many mine soils. The purpose of this study was to contrast after 15 years the growth, survival, and overall performance of seven hardwood species planted on three mine sites in Southwestern Virginia. The seven hardwood species were divided into species groups of a non-native fuelwood species, upland hardwoods, riparian species, and a valuable but off-site hardwood species. Overall tree performance was examined as a function of mine soil chemistry and fertility. Eastern cottonwood grew fastest, and black walnut grew slowest. By age 15, the native hardwoods, white and northern red oaks and yellow poplar, grew better than the American sycamore and white ash riparian species. They also responded to a mine soil fertility gradient while the others did not. The overall forest capability of the post-mined condition of these sites was far less than the pre-mined capability. The average weighted site indices (by extent of all soil series) of 10,000 acres in the vicinity of the mined sites are 82 and 77 for yellow poplar and northern red oak, respectively. Reduction in yellow poplar site index between the pre- and post-mined capability was 26 feet, and the difference for red oak was 15 feet. Northern red oak, white oak, and yellow poplar, all upland native commercial hardwood species, would be better choices for general reforestation than riparian species; however, better reclamation procedures then those used when this study was established (compacted mix of overburden materials with heavy herbaceous ground cover) are needed to restore forest land capability to pre-mining conditions.

Additional Key Words: reclamation, mine soil quality, site index

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Introduction

Prior to the introduction of the Surface Mining Control and Reclamation Act (SMCRA), many mined sites in the Appalachian and Midwestern coalfields were planted with native hardwood species (Ashby, 1996; Rodrigue et al., 2002). Pre-law sites were normally loose overburden with variable soil properties, but they usually provided a good growing medium for trees (Ashby, 1998; Rodrigue and Burger, 2004). Once the SMCRA was passed, reclamation of mined sites was mandated and mined sites had to be returned to approximate original contour (SMCRA, 1977). In addition, the law required that the land be returned to its original use and land capability (Section 515(b)(2), SMCRA, 1977). To achieve these mandates, grading of slopes became a common practice, and soil compaction, runoff, and erosion become a major issue (Burger, 1999). Erosion control groundcovers greatly competed with trees for soil resources, and compaction of the graded land caused rooting problems (Andersen et al., 1989; Burger, 1999). These limitations continue to impede reforestation in the Appalachian coalfields, and researchers and practitioners are seeking solutions to the problem of repeated reforestation failures to include selection of the best tree species for mined land conditions.

Several studies have been conducted using various tree species for surface mine reclamation. Many aspects of species performance, including survival, rate of growth, and economic feasibility, have been examined to develop options for landowners and companies for restoring native forests and making their land as productive as possible (Plass and Powell, 1988). Eastern white (*Pinus strobus* L.), loblolly (*Pinus taeda* L.), and Virginia pines (*Pinus virginiana* Mill.) are conifer species that can grow as well on mine soils as on undisturbed sites when mine soil conditions are properly managed (Torbert et al., 2000). However, the natural vegetation of the Appalachian region is primarily hardwoods. In recent years, several researchers have recommended reforestation using native hardwoods and reviewed the practices that would ensure their success (Ashby, 1999; Burger et al., 2008).

Rodrigue et al. (2002) compared hardwood growth on reclaimed sites to that on undisturbed sites and found similar production rates when mine soils were of good quality. Ashby (1996) also reported good growth for black walnut, oaks, and several other native hardwood species on pre-law overburden in the Midwest, but post-law reforestation was largely unsuccessful (Ashby, 1996). Groninger et al. (2006), in a survey of reforestation success at 22 post-law mines in Indiana, found that most sites were too compacted to support native hardwoods. Black locust and green ash were the dominant species surviving, and average oak site index was only 30 feet at age 50 versus 60 to 70, which is common on medium quality undisturbed sites in the region. This shows that mined site quality greatly limits forest productivity and the tree species that can survive on mined sites reclaimed since the implementation of the SMCRA. Similar observations on the adverse effects of post-law reclamation on tree survival and productivity were made in the Appalachian region (Torbert et al, 1985; Kost et al. 1998). On the other hand, in a recent study in Southwest Virginia, Burger et al. (2008) reported excellent survival and growth for several hardwood species, including white ash, yellow poplar, red oak, and white oak, on good quality mine soils where competing groundcover vegetation was controlled using herbicides. This study suggests great promise for native hardwoods; however, there is limited research on the soil factors limiting the survival and growth of specific species. In 1992, a tree species trial consisting of seven species (yellow poplar, eastern cottonwood, northern red oak, white ash, black walnut, American sycamore, and white oak) was established on a recently reclaimed surface mine in Wise County, Virginia, to compare survival, growth, and overall tree performance, and to determine relative tree growth as a function of mine soil chemistry and fertility 15 years after establishment.

Methods and Procedures

The species trial was established on three different Wise County, Virginia, sites that had been surfaced-mined for coal in 1990 and reclaimed in 1991 using standard reclamation practices. The mined sites were graded and tracked and sown with erosion control ground covers that included tall fescue, orchardgrass, and serecia lespedeza. Mine soils consisted of a mix of sandstone and siltstone overburden materials that were only moderately compacted on steep slopes. Slopes ranged from 39% to 50%, and slope aspect varied from northwest to southeast. Trees were planted in March, 1992. Seven species, including northern red oak (*Quercus rubra* L.), white oak (*Quercus alba* L.), white ash (*Fraxinus americana* L.), black walnut (*Juglans nigra* L.), cottonwood (*Populus deltoides* Bartram ex Marsh.), American sycamore (*Platanus occidentalis* L.), and yellow poplar (*Liriodendron tulipifera* L.) (same as tulip poplar), were planted as 2-0 seedlings. Seedlings were obtained form the Virginia Department of Forestry tree nursery. The trees were planted at 14 x 14-foot spacing in 3 rows per species with 8 trees per row to create single-species plots of 24 trees. The experimental study was a randomized complete block design with three blocks (replications) on three different mined sites (yellow poplar was planted on blocks 1 and 3 only). The block design accounted for possible variation in tree growth due to site differences. In order to simulate operational conditions, no maintenance or stand improvement operations were conducted on the sites. The agricultural erosion control grasses and legumes sown prior to tree planting were dense and competitive during the entire study period. They included tall fescue (*Festuca arundinacea* Schreb.), orchardgrass (*Dactylis glomerata* L.), redtop (*Agrostis gigantean* Roth), perennial ryegrass (*Lolium perenne* L.), red clover (*Trifolium pretense* L.), and serecia lespedeza (*Lespedeza cuneata* (Dum.-Cours.) G. Don). They nearly provided 100% ground cover and were two to three feet tall on all three sites; they began to lose some vigor after 10 to 12 years when the trees closed canopy.

Tree height was measured in the early spring of 2007 using a clinometer or meter pole depending on height, and diameter was measured at breast height using a diameter tape. Survival rate was calculated by comparing surviving trees with the number planted in 1992. Differences in tree survival, height, and diameter among species and species groups were analyzed using ANOVA (SAS, 2001). For evaluation and analysis purposes, species were grouped by site type and potential commercial value to include the following groups: 1) non-native fuelwood (eastern cottonwood), 2) high-value hardwood requiring fertile sites (black walnut), 3) medium-value hardwoods adapted to upland, average-quality sites (northern red oak, white oak, yellow poplar), and 4) low-value hardwoods found in bottomlands or riparian environments (American sycamore and white ash). Analysis of variance among groups was done with SAS Proc GLM (SAS, 2001) which accommodates unequal sample sizes.

Three soil sub-samples were taken randomly within each species plot and composited. Soils were analyzed for nitrogen and carbon content using a CRN analyzer (Vario MAX, Elementar MAX Instruction Manual 2000). Plant-available macro- and micronutrients were determined using Mehlich I extraction and ICP spectroscopy (SpectroFlame Modula Tabletop ICP, Spectro Analytical Instruments Inc., Fitchburg, MA). Soil reaction (pH) was measured in a 2:1 water:soil solution and cation exchange capacity (CEC) was calculated by summing the charge contributed by exchangeable Ca, Mg, K, and Na concentrations. Correlations between volume index (d^2h) and soil fertility variables were tested using correlation statistical procedures in JMP statistics software (SAS, 2001).

Results and Discussion

Tree Survival

Species 15-year survival rates ranged from 54.2% (yellow poplar) to 76.4% (eastern cottonwood). Overall, all species survived equally well, as there were no significant differences in survival among species or between species groups (Fig. 1). Eastern cottonwood was the only species that exceeded the 70% survival rate, which is a target level used to judge successful reforestation (Burger et al, 2008). Yellow poplar survival was lowest, which was consistent with reports by Ashby (1996) and Cleveland and Kjelgren (1994) showing that yellow poplar survival is variable and site-specific. Survival of the remaining species averaged around 60%, which is a bit lower than expected under average conditions of site and seedling quality and season-to-season climatic variation.

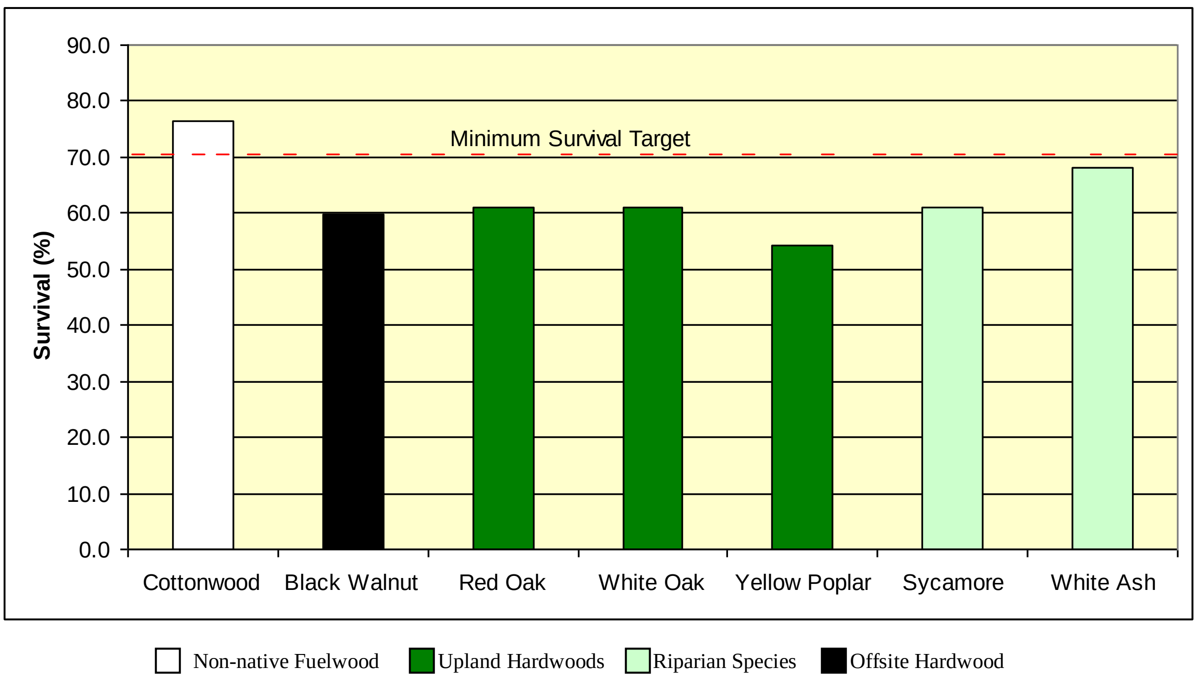

Figure 1. Fifteen-year survival rate (%) of seven hardwood species and groups of upland hardwoods, offsite hardwood, non-native fuelwood, and riparian hardwood species on a species trial in Southwestern Virginia.

Tree Growth

Relative tree growth was evaluated using tree height, diameter, and a tree volume index estimated as the product of the height and the square of the diameter (d^2h). Tree height and diameter varied partly as a function of species type, and partly as a function of species response to the mine soil environment. Eastern cottonwood height and diameter, 42.01 ft (Fig. 2A) and

7.45 in (Fig. 2B), respectively, exceeded all other species because it is a fast-growing, early-successional species. It grew at a poor rate (SI = 60, base age 25 years) relative to its performance on undisturbed, bottomland sites (SI=70 or more, base age 25 years) (Meyers and Buchman, 1984). Cottonwood is commonly found and does best on moist alluvial sites along streams and across broad river bottoms. Despite its relatively poor growth, cottonwood may be a good candidate for fuelwood plantations if and when such enterprises become viable at a local level. It is native to Virginia, but not common in the Appalachian region.

Black walnut survived well, but it grew very poorly (Fig. 2ABC). This was consistent with other species trials on Appalachian mined sites (Torbert et al., 1985; Skousen et al., 2009). Black walnut has been used effectively on midwestern mined sites (Ashby, 1996), but it is unlikely that it will be useful as a valuable timber tree on mined sites in the Appalachians. It is native to the Appalachians, but on upland sites, it seldom has the required form or growth rate to be a commercially-viable timber tree, even on undisturbed sites.

The average height of the upland hardwoods (northern red oak white oak and yellow poplar) was around 20 ft, and the riparian species (white ash and American sycamore) had an average height around 17 ft (Fig. 2A). The average diameter was 4.0 in for the upland species and 2.8 in for the riparian species (Fig. 2B). Upland hardwoods and riparian species both showed good growth (Fig. 2C), but the upland species appeared to be growing slightly better, although the volume index was not significantly different. White ash and American sycamore have long been considered reclamation species because of their good survival and good early growth, despite the fact that they are largely riparian species and functionally off-site on an upland mined site environment. As early-successional pioneer species, they naturally grow quickly when seeded or planted, and we speculate that they do well on mined sites because they can tolerate poorly drained and poorly aerated soil conditions, which are characteristic of compacted mine soils. Our results show, however, that the upland species will eventually outgrow the off-site riparian species as they become established and reach stand closure. This is an important finding because it shows that the valuable oaks and tulip poplar can do well provided they are planted on reasonably productive mined sites and protected from excessive ground cover vegetation. With time, they have the potential to develop into a valuable forest stand and are better suited for the upland environment of most mined sites.

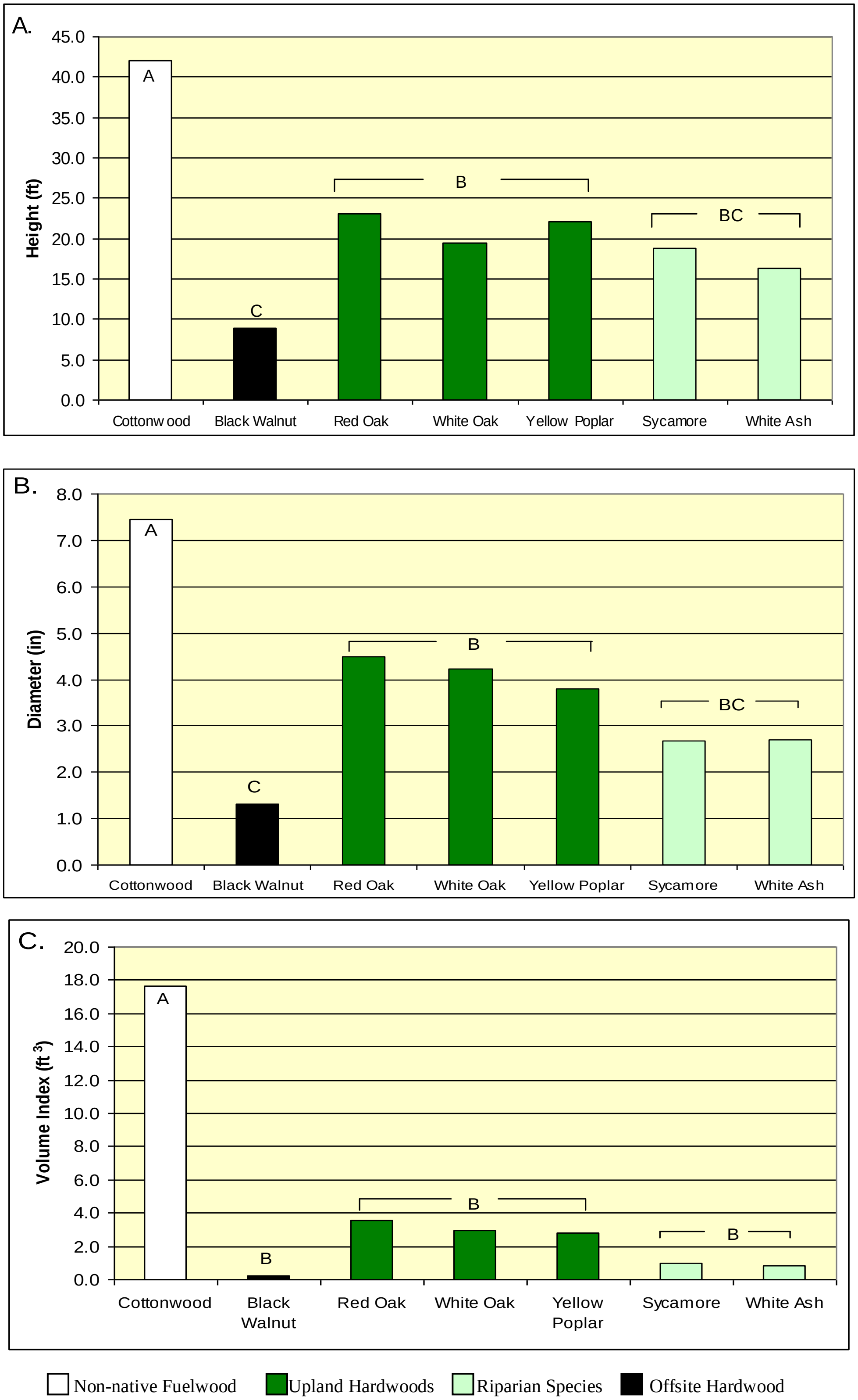

Figure 2. Height (A), diameter (B), and volume index (C) of seven species in Wise County, Virginia, with corresponding species groupings (different letters among species or species groups indicate significant differences (P<0.1)).

Soil Fertility

Soil compaction from heavy grading of mine soil surfaces may be the greatest impediment to the success of native hardwoods, but as mine operators change their practices to accommodate forestry post-mining land uses with deeper and looser mine soils, soil fertility may become the factor controlling or limiting hardwood growth (Bendfeldt et al., 2001). Among the three replicate sites, soil chemistry and fertility varied. Site 1, especially, had higher pH, Ca, CEC, and base saturation (BS) levels, but N and P also varied among sites (Table 1).

Table 1. Soil properties of three surface mine sites in Southwestern Virginia by species plots.

Species	**pH**	**N**	**C**	**OM**	**P**	**K**	**Ca**	**Mg**	**Soluble Salts**	**CEC**	**Base Sat**
		(%)	(%)	(%)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(ppm)	(meq/ 100g)	(%)
Site 1											
Red oak	6.64	0.197	3.96	5.2	33	55	2066	203	128	12.2	99.6
Yellow poplar	7.18	0.219	3.52	5.5	22	66	1994	232	115	12.0	100
Black walnut	6.85	0.169	2.71	4.3	19	63	1370	230	102	8.9	99.4
White oak	7.19	0.207	3.30	4.9	16	66	2028	233	141	12.2	100
Sycamore	7.02	0.246	3.81	5.8	30	62	1604	243	115	10.2	100
White ash	7.02	0.226	4.07	6.3	23	72	1872	231	115	11.4	100
Cottonwood	7.04	0.218	3.59	5.9	17	73	1796	257	115	11.2	100
Mean	**6.99**	0.212	3.57	5.4	23	65	**1818**	233	119	**11.2**	99.9
Site 2											
Red oak	5.54	0.196	3.20	5.3	14	80	704	219	77	8.2	66.9
Black walnut	6.10	0.223	3.75	5.4	24	94	959	288	90	8.5	86.8
White oak	6.13	0.250	4.20	8.2	19	77	1090	285	102	9.4	84.3
Sycamore	6.10	0.240	4.08	6.7	20	85	1114	297	102	9.3	88.5
White ash	5.63	0.167	2.84	4.2	14	85	694	220	77	7.3	75.5
Cottonwood	6.12	0.208	3.42	5.3	18	122	1049	275	102	8.9	87.4
Mean	**5.94**	0.214	3.58	5.9	18	91	**935**	264	92	**8.6**	81.6
Site 3											
Red oak	5.55	0.145	2.37	4.0	7	66	573	116	51	5.8	69.1
Yellow poplar	5.10	0.122	1.91	3.8	3	66	374	82	51	6.6	40.8
Black walnut	5.14	0.101	1.69	3.4	2	61	406	86	38	6.9	42.1
White oak	5.66	0.171	2.91	4.8	8	107	867	184	64	7.9	77.4
Sycamore	5.66	0.209	3.32	6.4	7	89	861	179	64	8.5	70.6
White ash	5.60	0.180	2.62	5.4	5	81	838	154	64	7.3	77.3
Cottonwood	5.76	0.159	2.42	5.2	6	138	860	159	77	7.6	78.8
Mean	**5.49**	0.155	2.46	4.7	5	87	**683**	137	58	**7.2**	65.2

Eastern cottonwood volume was negatively correlated with N, P, and C, which is counter-intuitive; therefore, some other factor such as inadequate soil water may have been responsible for its overall poor growth compared to its potential on moist alluvial sites where it is commonly found (Table 2). The growth of the riparian species, white ash and American sycamore, was positively correlated with pH and Ca levels, suggesting that these species prefer less acidic soil environments. The growth of the upland hardwoods, red and white oaks and tulip poplar, was positively correlated with pH, Ca, P, CEC, BS, and soluble salts, showing a clear affinity for more fertile sites. The poor growth of black walnut may have been related to inadequate N and P, as suggested by the positive correlations, but inadequate soil water probably played a greater role given its high soil water requirements.

Table 2. Significant correlations of species group volume index as a function of soil chemical and fertility properties (Proc Corr, SAS 2001).

Species Groups	Soil Property	Correlation Coefficient	Probability Level
Non-native (cottonwood)	N%	-.9967	.0520
	C%	-.9983	.0366
	P	-.9884	.0971
Riparian Hardwoods (white ash & sycamore)	pH	.8037	.0540
	K	-.8105	.0505
	Ca	.7795	.0675
Upland Hardwoods (red oak, white oak, yellow poplar)	pH	.8230	.0121
	P	.6874	.0596
	Ca	.8973	.0025
	CEC	.8104	.0147
	Base Sat	.7980	.0176
	Soluble Salts	.7816	.0220
Offsite (black walnut)	P	.8866	.0524
	Mg	.9998	.0117
	N%	.9878	.0997

Volume growth rates of the upland species (red and white oaks and tulip poplar) and the native riparian species (ash and sycamore) were regressed (simple linear regression) with indicators of soil fertility including pH, CEC, and Ca (Fig. 3, 4, and 5). As these soil properties increased in value, growth of the upland species increased considerably. Tree volume increased threefold across a pH gradient ranging from 5.5 to 7; a CEC gradient ranging from 6 to 12 $cmol^{+}\ kg^{-1}$; and a Ca gradient ranging from 500 to 2000 $mg\ kg^{-1}$. These soil properties are related to one another, so it is not possible to discern which is most influencing tree growth. However, they are all related to soil acidity and nutrient availability and collectively suggest that increasing soil fertility dramatically improved the growth of these three species. The pH, CEC, and Ca gradients had little or no effect on the native riparian species. These species have approximately the same nutrient requirements as the upland species and are known to thrive at near-neutral pH and high fertility conditions. Their inability to respond to increasing fertility is probably due to stress associated with limited soil water on these upland sites, exacerbated by the constant competition for water by the agricultural grasses sown for erosion control.

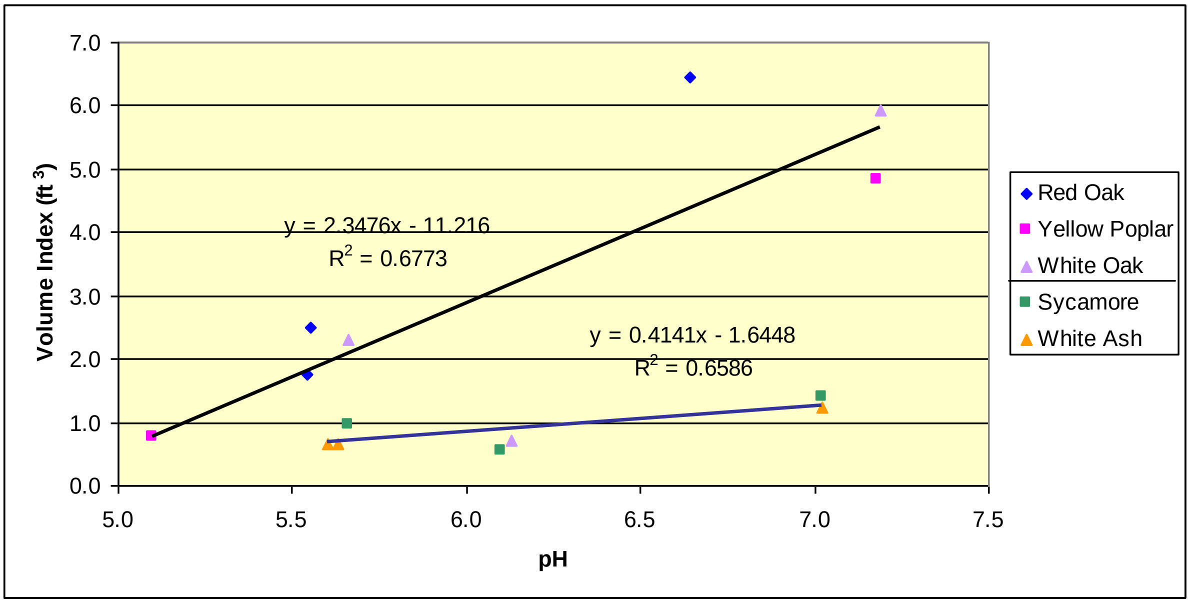

Figure 3. Volume index of upland hardwoods (red oak, yellow poplar, and white oak) and riparian species (sycamore and white ash) as a function of soil pH.

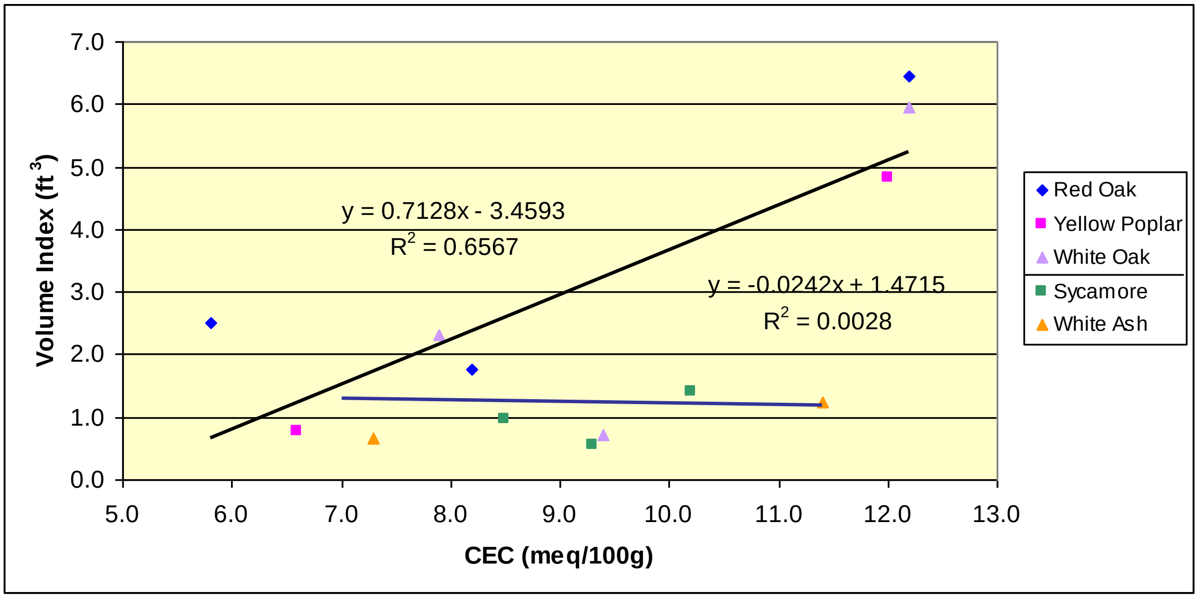

Figure 4. Volume index of upland hardwoods (red oak, yellow poplar, and white oak) and riparian species (sycamore and white ash) as a function of soil CEC.

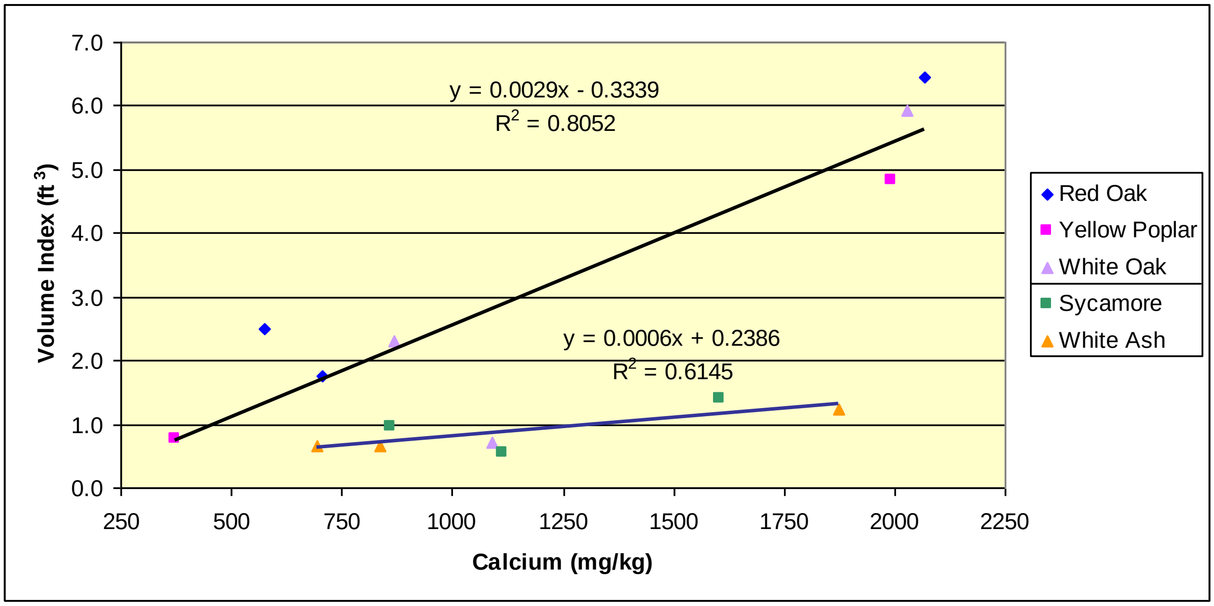

Figure 5. Volume index of upland hardwoods (red oak, yellow poplar, and white oak) and riparian species (sycamore and white ash) as a function of soil Ca concentration.

These results demonstrate that over the long run the native upland species were more suited to the mined land conditions than the ash and sycamore, despite the riparian species' tendency to grow faster during the first 5 years after planting. The upland species are far more valuable as a timber crop than the riparian species. Except for possible infestation of the oaks by the gypsy moth at some future date, these upland species are relatively low risk choices for reclamation. White ash has value, but it is threatened by the imminent invasion of the emerald ash borer, a serious pest killing the ash in the Northeast and Midwest U.S. Coal operators and reclamation specialists like planting ash and sycamore because they survive well and have a fast early growth habit. This study shows that the upland species survive equally well and grow better over the long run, and landowners will benefit from their higher value.

Site Productivity

The average productivity of the reclaimed mined sites was site index 56 ft (age 50) for both tulip poplar and red oak (Fig. 6) (Carmean et al., 1989). Site index (SI) is the most common way of estimating the capability or yield potential of forest land. It refers to the height of dominant or co-dominant trees in a forest canopy at a designated age, usually age 50 for eastern hardwoods and age 25 for conifers and other fast-growing trees such as eastern cottonwood (Avery and Burkhart, 2002). For example, on good sites, red oak will attain a height of 80 feet in 50 years

(SI = 80), and on poor sites, a height of 50 feet in 50 years (SI = 50). Site index is species-specific; some trees grow taller than others on the same site. Therefore, yellow poplar would have a SI=85 on the good site but may not be higher than red oak on poor sites because it is more site-sensitive. Of course, tree height is closely correlated with wood yield of forest land, so it is equivalent to using bushels of corn per acre to measure cropland capability.

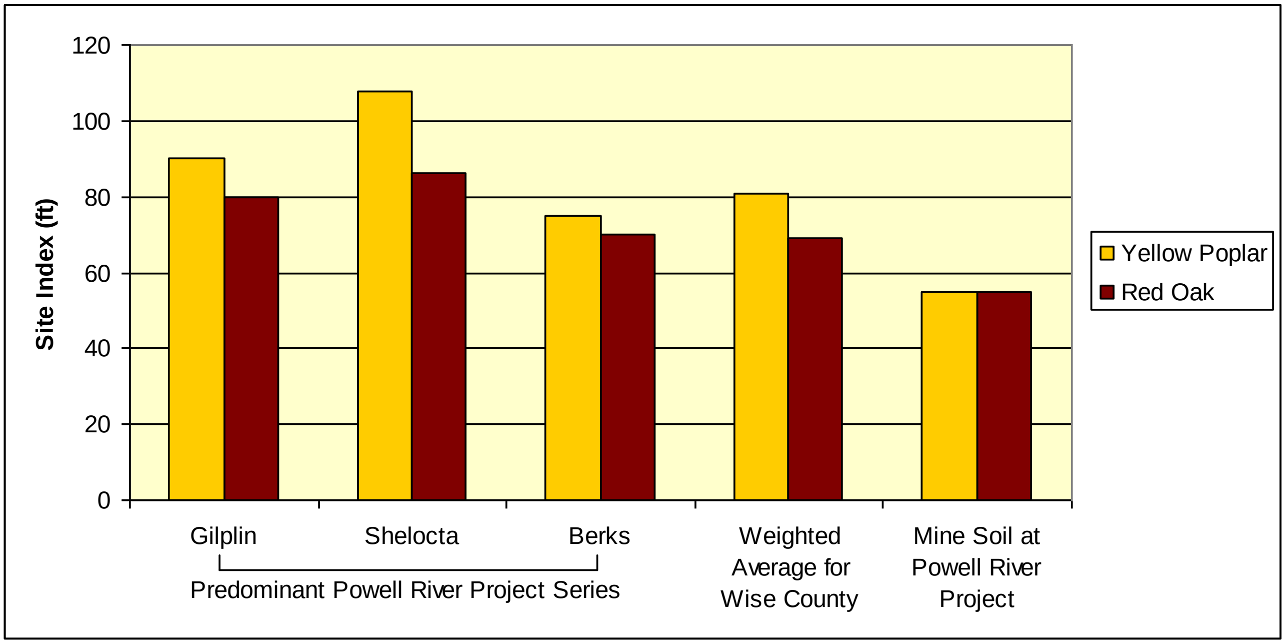

Figure 6. Forest site indices of predominant soil series in the study area, a weighted average of site index for the Jefferson National Forest in Wise County, Virginia, and yellow poplar and red oak site indices of reclaimed mine soils on the Powell River Project Demonstration Area.

The data in Fig. 6 show that the capability of the post-mining condition is considerably less than the forest capability of the predominant soil series that existed prior to mining. The tulip poplar site indices for the Gilpin, Shelocta, and Berks soils are 90, 107, and 77, respectively, compared to SI 56 for the reclaimed sites. These soil series are derived from shales, siltstones, and fine grained sandstone and occur throughout the Appalachian coalfields. The average weighted (by extent of all soil series) site index of 10,000 acres in the vicinity of the mined sites is 82. Therefore, the difference in tulip poplar SI between the pre- and post-mined capability is 26 feet, and the difference for red oak is 15 feet.

The difference in capability or forest yield between the pre- and post-mined conditions is greater than the SI or tree height data suggest. As trees increase in height, the diameter of the stems, or tree trunks, increases roughly exponentially (d2h) (Avery and Burkhart, 2005). Therefore, the wood yield and value are proportionately greater for large trees (high SI) than for small trees (low SI). Extrapolating from data by Fox (2002), the oak sawtimber volume of a mature fully-stocked oak forest on these pre-mined sites (SI = 77) would be approximately 12,000 board feet per acre (bf/ac), and about 4,000 bf/ac after mining (SI = 56). Because the wood in large trees on good sites is worth more than the wood in smaller trees on poor sites, the stumpage value is higher for the trees on the good sites ($363 versus $266 based on 2002 prices as reported by Fox). Therefore, the timber capability value for the pre-mined sites is $4,392/ac compared to $1,064/ac for the post-mined sites, a fourfold reduction in capability. Nonetheless, the upland species (red and white oaks and tulip poplar) used in this study will eventually be far more valuable than the white ash, American sycamore, eastern cottonwood, and black walnut, despite the fourfold reduction in post-mining forest land capability. The study shows that the more valuable upland species should be planted on most mined sites rather than the commonly-planted riparian species because the upland species eventually grow better and are more valuable. Although overall growth rates were lower than average rates expected for pre-mining conditions, reduced compaction and the use of tree-compatible ground covers would likely improve the performance of these upland species on reclaimed mined land. A forestry reclamation approach that includes best practices for restoring native hardwoods on mined land is outlined by Burger and Zipper (2009) and Burger et al., 2005).

Conclusions

Reforestation of mined land is becoming more commonplace as landowners become aware that reforesting their previously forested land is the most economically-viable post mining land use (Probert, 1999). Researchers and coal operators are also finding that reclamation procedures geared for reforestation are less expensive than traditional reclamation procedures used for establishing grassland (Burger and Zipper, 2009). This renewed interest in mined land reforestation prompted us to study the capability of mine soils for tree species that provide the best value for landowners while restoring native forest diversity for other ecosystem values.

The results of this 15-year-old species trial on traditionally-reclaimed (compacted with agricultural grasses and legumes used as ground cover) mined land shows that native upland tree species, including red and white oaks and yellow poplar, outperformed white ash and American sycamore riparian species that have been preferred reclamation trees because of their fast early growth. With time, the drought-tolerant upland species, which happen to be far more commercially valuable, grew better and have good potential as components in mixed native hardwood stands.

The overall forest capability of the post-mined condition of these sites was far less than the pre-mined capability. The average weighted (by extent of all soil series) site indices of 10,000 acres in the vicinity of the mined sites are 82 and 77 for yellow poplar and red oak, respectively. Therefore, the difference in yellow poplar SI between the pre- and post-mined capability was 26 feet, and the difference for red oak was 15 feet. The timber capability value for the pre-mined sites was $4,392/ac compared to $1,064/ac for the post-mined sites, a fourfold reduction in capability. Nonetheless, as these trees mature, the upland species (red and white oaks and yellow poplar) will be far more valuable than the ash, sycamore, cottonwood, and black walnut, despite the fourfold reduction in post-mining forest land capability. As coal operators fully employ the forestry reclamation practices advocated by the Office of Surface Mining's Appalachian Regional Reforestation Initiative (Burger et al., 2005), pre-mining forest capability should be restored as the SMCRA requires.

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