INFLUENCE OF SITE FACTORS ON THE SURVIVAL AND GROWTH OF EARLY- AND LATE-SUCCESSIONAL APPALACHIAN HARDWOODS ON RECLAIMED MINED LAND[1]

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Abstract. In recent years, there has been an upsurge of interest in mined land reforestation with an emphasis on restoring native hardwood species. Research shows that most Appalachian hardwoods could be established on pre-SMCRA sites, but field observations show that many species cannot tolerate the conditions of post-law sites. The purpose of this study was to compare the survival and early growth of hand-planted early- and late-successional timber species (hereafter called softwoods and hardwoods, respectively) as a function of site, specifically slope steepness and slope aspect. This study was conducted on ten sites located in a three-state region of the southern Appalachian coalfields. Four softwoods (American sycamore, green ash, red maple and tulip poplar) and six hardwoods (black cherry, black walnut, northern red oak, sugar maple, white ash, and white oak), all native to the region, were used in the study. Average survival for softwoods was about 50% compared to hardwoods at 38%. Softwoods were also more productive than hardwoods across sites. Softwood survival increased as a function of increasing slope ($P < .0005$) and sunny aspects ($P < .0001$). Softwood tree volume also increased as a function of increasing slope ($P < .0001$) and sunlight ($P < .0008$). Hardwood survival and tree volume were not correlated with either slope or aspect. Because of adverse site conditions, hardwoods as a group did not perform well enough to meet regulatory performance standards. The results of this study demonstrate that hand-planted softwoods, while less viable commercially, survive and grow better than hardwoods. Better reclamation techniques are needed to establish native hardwoods successfully in the Appalachian coalfields.

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Introduction

Surface mining for coal has been ongoing in the Appalachian region since the early 1900s, with widespread mining commonplace by the 1950s in the form of strip mining. As long as 60 years ago, it was shown that strip-mining is the safest and most economical method of extracting coal from mountainous terrain (Tyner and Smith, 1945). It appears that it will continue to be the dominant mining method for years to come, leaving large areas of mined land that will ultimately have social, economic, and ecological impacts on the region.

The most common revegetation practice in the Appalachian coalfields is the sowing of grasses and legumes for erosion control (Davidson et al., 1984; Farmer Jr. et al., 1982; Li and Daniels, 1994; Torbert and Burger, 2000). Recently there has been a major shift, from this agriculturally-based reclamation, towards regenerating forests on mine soils, which occasionally includes the establishment of hardwood timber-producing species on post-SMCRA sites. Research on pre-SMCRA reclaimed and abandoned mine soils has shown that the following tree species will survive and grow on disturbed sites: black walnut (*Juglans nigra*), red oak (*Quercus rubra*), white oak (*Q. alba*), green ash (*F. pennsylvanica*), white ash (*Fraxinus americana*), red maple (*A. rubrum*), sugar maple (*Acer saccharum*), white pine (*Pinus strobus*), Virginia pine (*P. virginiana*), sweetgum (*Liquidambar styraciflua*), black cherry (*Prunus serotina*), tulip poplar (*Liriodendron tulipifera*), and black locust (*Robinia pseudoacacia)* (Ashby et al., 1980; Beckjord and McIntosh, 1984; Cunningham and Wittwer, 1984; Lawrey, 1977).

Although early-successional species such as white pine, Virginia pine and black locust have been successfully established on post-SMCRA mind land, the use and performance of commercially-valuable native hardwoods has not been extensively tested. Post-SMCRA reclamation entails the use of heavy equipment to shape and level the reclaimed surface followed by the establishment of dense herbaceous ground cover. The equipment compacts the mine soil, and the ground cover vegetation competes with trees for water and nutrients. Research has shown low water-holding capacity and poor growing conditions result from the use of stock-piled soils and large earth-moving equipment (Abdul-Kareem and McRae1984; Gildon and Rimmer, 1993; Harris and Birch, 1989; Hower et al., 1992; Pedersen et al., 1980). Herbaceous ground covers are used for erosion and sediment control, but they can severely limit tree survival and growth (Kundu and Ghose, 1998; Thompson and Wade, 1991; Torbert and Burger, 2000).

Survival rates have been shown to increase by 6% and 19% when weed suppression was used on sites in the Midwest (Byrnes et al., 1980). Natural site factors such as slope steepness and aspect can also affect survival and growth of different species, but it is not clear how these factors interact with post-SMCRA reclamation practices in ways that affect tree establishment. The purpose of this study was to investigate the survival and early growth of hand-planted early- and late-successional native tree species on ten post-SMCRA sites as a function of site factors, specifically slope steepness and slope aspect.

Materials and Methods

The study consisted of ten post-SMCRA mined sites in Virginia, West Virginia, and Kentucky (Table 1). The sites were installed during a two-year period between April 1996 and April 1998. Trees were planted on 3.2 by 3.2 meter spacing for a total of 1000 trees per hectare. Sites were chosen, in part, on the basis of aspect, slope steepness, and spoil type. Sites ranged from grey sandstone (Inez, Kentucky) to shale (Wise, Virginia), with aspects of southwest, south/southwest, north, and mountain-top/flat (Rainelle, West Virginia) (Table 1).

Table 1. Description and characteristics of study sites.

Number	Site	Aspect	Slope (%)	Spoil Type
1	Inez, KY	southwest	36	grey/brown sandstone
2	Inez, KY	south/southwest	25	grey sandstone
3	Inez, KY	north	23	grey sandstone
4	Wise, VA	flat	2	shale
5	Wise, VA	north	19	grey/brown sandstone w/small amount of shale
6	Inez, KY	north	39	brown/grey sandstone
7	Gilbert, WV	flat	9	brown sandstone
8	Gilbert, WV	north	48	brown sandstone
9	Leivasy, WV	southwest	35	brown sandstone/shale
10	Rainelle, WV	mountain-top/flat	10	brown sandstone/shale

Heights and ground-line diameters of all trees were measured for five years following establishment. Survival was defined as the percentage of each tree species remaining five years after reclamation. The significance of site, slope, and aspect on the survival, height, and tree volume (dm^3) produced by both softwoods and hardwoods was tested using a randomized complete block design (RCBD) at the α = .10 level (SAS, 1985). A topographic site model, incorporating aspect and slope, was used to determine whether these factors were correlated with tree survival and volume. R-squared values are shown as an estimate of the amount of variation explained by the models.

To quantify aspect, we used a model described by Auchmoody and Smith (1979). This model expresses aspect as the cosine of azimuth with a phase shift angle of 81° from north, which is modified by slope gradient. The slope cosine transformation imposes approximate linearity between site index and azimuth. The phase shift angle of 81° places the best sites at N81°E and the least productive at S81°W, a shift of 23° to 35° further east than the normal 45° to 58° shift used for adjustment in most other soil-site investigations. Appropriate transformed cosine values for plot azimuth having a phase shift angle of 81° were as follows: (1) north = 0.1564, (2) flat = 0.0000, (3) south = -0.1564, and (4) southwest = -0.8090 (Auchmoody and Smith, 1979).

Results

Softwood survival among species was similar and averaged 50% (Table 2). It varied from about 25% on site 7 to approximately 75% on site 9. Stocking varied with survival across sites, but there were no differences among species. Overall stocking was 518 trees/ha (208 trees/ac), which is about half of what is needed to meet performance standards in most Appalachian states. Average tree height (63 cm) was also the same among species. It varied somewhat among sites from a species average of 25 cm on site 7 to a species average of 125 cm on site 8. Tree volume index, the product of diameter squared and height, was greatest for red maple at 19494 dm^3 and the least for sycamore at 13507 dm^3. Tree volume varied among sites along with differences in tree diameter (data not shown).

Hardwoods, including black cherry, black walnut, red oak, sugar maple, white ash, and white oak, grew equally on average (Table 3). They all varied across sites, but there were no differences in survival, stocking, and tree height among species. Sugar maple had the greatest volume at 5121 dm^3 and black cherry had the lowest volume at 2480 dm^3. As a group, the softwoods performed better than the hardwoods (Table 4). Softwood average survival was 50% compared to hardwood average survival at 38%. Stocking and tree height of hardwoods were about half that of softwoods, while hardwood tree volume was only 23% of softwood tree volume.

Table 2. Softwood survival (%), stocking (trees/ha), height (cm), and volume (dm^3) across sites.

Species	**Performance***	**Site 1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**Stand Average**
American sycamore	Survival	80 a	58 abc	54 abc	40 bc	59 abc	31 c	27 c	54 abc	75 ab	33 c	51 a**
	Trees/ha	158	133	99	15	124	104	54	193	252	84	128 a
	Ht. (cm)	65 bc	83 b	37 d	50 cd	53 cd	71 bc	29 d	116 a	69 bc	30 d	60 a
	Vol. (dm^3)	8847 b	19857 b	3079 b	4804 b	5792 b	16041 b	1847 b	55916 a	17048 b	1840 b	13507 b
Green ash	Survival	60 abc	66 ab	54 abc	42 bcd	39 cd	41 bcd	25 d	61 abc	71 a	24 d	48 a
	Trees/ha	158	128	138	74	119	128	64	207	237	64	131 a
	Ht. (cm)	88 abc	72 bcd	54 de	40 ef	43 def	100 ab	27 ef	106 a	70 cd	25 f	63 a
	Vol. (dm^3)	12921 bc	14497 bc	4199 c	4717 c	2735 c	39562 ab	1685 c	47225 a	16287 bc	1785 c	14561 ab
Red maple	Survival	55 ab	60 ab	56 ab	38 abc	44 abc	51 abc	26 bc	51 abc	72 a	19 c	47 a
	Trees/ha	124	138	138	79	94	143	54	178	247	49	124 a
	Ht. (cm)	64 bc	63 bc	50 cd	49 cd	48 cd	92 b	29 d	130 a	80 bc	21 d	63 a
	Vol. (dm^3)	9255 b	8044 b	3704 b	6758 b	3633 b	28253 b	2633 b	78588 a	23149 b	918 b	16494 a
Tulip poplar	Survival	72 a	72 a	55 abc	39 bc	48 abc	40 bc	25 c	59 ab	78 a	29 bc	52 a
	Trees/ha	158	138	119	89	104	114	59	212	262	84	133 a
	Ht. (cm)	74 bc	63 bc	52 cd	67 bc	51 cd	76 bc	32 de	119 a	78 b	22 e	63 a
	Vol. (dm^3)	13210 bcd	8877 bcd	4163 cd	16872 bc	3824 cd	21746 b	2580 cd	57829 a	23838 b	1201 d	15414 ab

*Tested at the $\alpha = .05$ level across the 10 sites for each performance measure.

** Stand average comparisons are across species for each performance measure.

Table 3. Hardwood survival (%), stocking (trees/ha), height (cm), and volume (dm^3) across sites.

Species	Performance*	Site 1	2	3	4	5	6	7	8	9	10	Stand Average
Black cherry	Survival	36 abc	51 ab	42 abc	33 bc	59 a	38 abc	24 c	52 ab	50 ab	31 bc	42 a**
	Trees/ha	59	114	79	59	74	109	40	104	89	35	77 a
	Ht. (cm)	44 ab	35 abc	39 abc	37 abc	47 ab	49 a	22 cd	50 a	31 bcd	17 d	37 a
	Vol. (dm^3)	2626 bc	2155 bc	2228 bc	1826 bc	2626 bc	3719 ab	1082 bc	6082 a	1789 bc	668 c	2480 c
Black walnut	Survival	40 abc	45 ab	44 ab	25 bc	33 abc	52 a	16 c	39 abc	43 ab	26 abc	36 a
	Trees/ha	69	104	94	49	69	109	30	84	89	40	74 a
	Ht. (cm)	44 ab	39 ab	22 b	38 ab	38 ab	55 a	32 ab	56 a	32 ab	18 b	37 a
	Vol. (dm^3)	2603 b	1632 b	555 b	4847 ab	2228 b	5849 ab	1803 b	8705 a	2024 b	502 b	3075 ab
Red oak	Survival	31 ab	30 ab	43 ab	26 b	25 b	61 a	27 b	57 ab	51 ab	42 ab	39 a
	Trees/ha	54	54	59	25	14	104	49	114	94	49	64 a
	Ht. (cm)	59 a	29 abc	30 abc	16 c	47 ab	48 ab	29 bc	53 ab	26 bc	17 c	35 a
	Vol. (dm^3)	10872 a	1560 b	1145 b	225 b	4122 ab	3968 ab	2912 ab	6709 ab	1759 b	394 b	3367 ab
Sugar maple	Survival	34 bcd	70 a	49 abc	18 d	22 cd	59 ab	24 cd	59 ab	49 abc	18 d	40 a
	Trees/ha	44	64	69	35	30	109	25	128	99	25	62 a
	Ht. (cm)	55 b	32 de	35 cd	5 f	73 a	61 ab	16 ef	50 bc	31 de	21 def	38 a
	Vol. (dm^3)	6276 ab	1689 b	2188 b	46 b	24416 a	8430 ab	504 b	5282 ab	1747 b	631 b	5121 a
White ash	Survival	40 a	42 a	25 a	21 a	34 a	47 a	32 a	43 a	42 a	24 a	35 a
	Trees/ha	69	64	40	35	54	109	49	89	79	30	62 a
	Ht. (cm)	43 abc	42 abc	30 cde	15 e	38 abcd	53 ab	34 abcde	54 a	34 bcde	21 de	36 a
	Vol. (dm^3)	1732 bc	2740 bc	1021 c	738 c	2265 bc	5842 a	2311 bc	6801 a	3430 b	1072 c	2795 c
White oak	Survival	41 ab	33 ab	42 ab	36 ab	26 ab	35 ab	23 b	53 a	38 ab	17 b	34 a
	Trees/ha	99	30	84	54	59	64	35	133	74	25	67 a
	Ht. (cm)	37 ab	40 ab	29 ab	34 ab	64 a	61 a	27 ab	56 ab	31 ab	20 b	40 a
	Vol. (dm^3)	1338 a	2350 a	1332 a	1771 a	11962 a	9003 a	1669 a	7935 a	2239 a	658 a	4026 b

*Tested at the $\alpha = .05$ level across the 10 sites for each performance measure.

**Stand average comparisons are across species for each performance measure.

Table 4. Softwood versus hardwood average survival (%), stocking (trees/ha), height (cm), and volume (dm^3) across sites.

Performance*	Softwood	Hardwood
Survival (%)	50 a	38 b
Trees/ha	131 a	67 b
Height (cm)	62 a	37 b
Volume (dm^3)	14994 a	3477 b

*Tested at the $\alpha = .05$ level.

Hardwood tree volume and survival were not correlated with either slope or aspect; however, softwood species survival increased as a function of increasing slope and aspect (Fig. 1). As slope increased, survival increased, and as aspect provided greater sunlight intensity and duration, survival also increased. About 40% of the variation in survival was associated with slope and aspect. The model is defined as follows:

$$\textbf{Survival} = 33.12311 + .48566\ (\text{slope}) + 30.97938\ (\text{aspect})$$

$$R^2 = .4054;\ \text{Slope-P} < .0005;\ \text{Aspect-P} < .0001$$

Softwood tree volume was also influenced by topographic factors. It was correlated with the two-way interaction between slope ($P < .0001$) and aspect ($P = .0008$) (Fig. 2). Approximately 53% of the variation in volume was associated with slope and aspect. The model is defined as follows:

$$\textbf{Volume} = -8802.05236 + 1100.63020\ (\text{slope}) - 22913\ (\text{aspect})$$

$$R^2 = .5272;\ \text{Slope-P} < .0001;\ \text{Aspect} < .0008$$

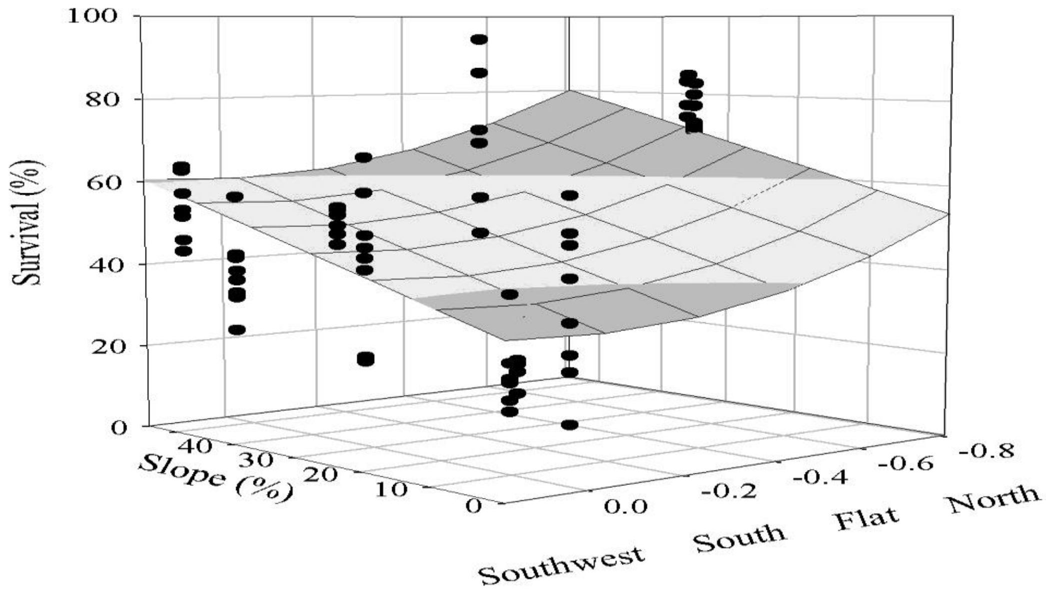

Figure 1. Softwood survival as a function of slope (%) and aspect (Auchmoody and Smith, 1979).

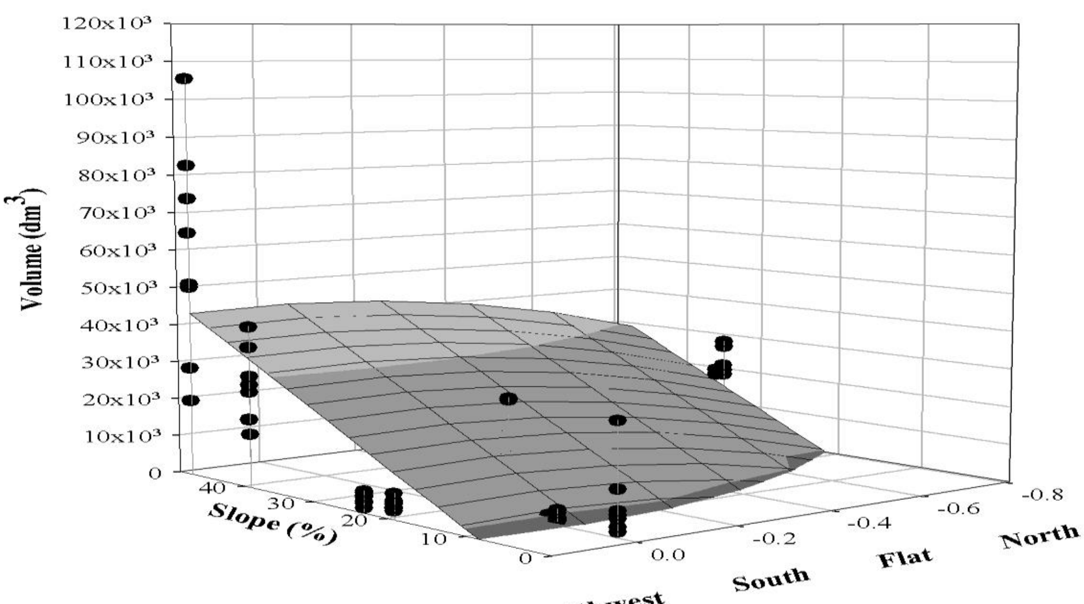

Figure 2. Softwood tree volume as a function of slope (%) and aspect (Auchmoody and Smith, 1979).

Discussion

This study shows that hand-planted native softwoods, while less important commercially, survive and grow better than native hardwood timber species. These results are in agreement with other studies indicating that hand-planted softwood trees are better able to out-compete the aggressive reclamation groundcover commonly sown for erosion control (Cunningham and Wittwer, 1984; Plass, 1976). Herbaceous groundcover competes intensively with trees for water and nutrients. Ground cover density across the study sites averaged 80% (data not shown), but there were no significant differences from site to site. Overall survival of the softwood species group was about 50%, compared to 38% for the hardwood group. Average overall stocking levels were about 500 trees/ha (200trees/ac). Neither species group survived well enough to meet performance standards required by most states.

There were surprisingly few performance differences among species within the softwood and hardwood groups. Cunningham and Wittwer (1984) found that direct-seeded oak was more productive then black walnut, but this study showed that hand-planted oak and walnut survived and grew about the same. This may be a result of the fact that these sites were more severely sloped and tended to be less compacted, which allowed better root penetration and water infiltration, two fundamental limitations found on most reclamation operations (Lyle, 1987; Riley, 1979; Voorhees et al., 1971). Overall, the softwood species survived and grew better on steeper slopes (Figures 1 and 2). This is counter-intuitive because steep slopes on undisturbed sites are usually droughty and shallow to bedrock. On mined sites, however, soil compaction usually decreases with increasing slope steepness (Andrews et al., 1998). Less compaction increases water infiltration and allows better root growth and exploitation of the rooting volume.

The softwood species group survived better on sunnier aspects, but grew less well on these aspects than the hardwood species. These early-successional species have an affinity for higher light intensities, but the south to southwest aspects probably had less available water, which caused the slower growth. Late-successional hardwood species normally respond to slope and aspect differences on undisturbed sites (Auchmoody and Smith, 1979), but competing vegetation and inappropriate mine soils may have limited their response to site factors.

The results of this study show that early-successional softwoods survive and grow better than late-successional hardwoods across a range of sites and under the influence of intense, competing herbaceous vegetation. The softwood species group was growing well enough to respond to increases in slope steepness and slope aspect, but these site factors had no influence on the hardwood species group. All ten study sites were graded and compacted to some extent, and some consisted of alkaline shales and sandstones that could limit tree growth. Further soil analysis will be needed to determine the influence on tree growth of the chemical, physical, and biological properties of the mine spoils represented in this study. A more complete understanding of soil properties will provide further insight on the characteristics of the sites that were suitable or detrimental to tree growth.

In conclusion, native softwoods and hardwoods are sensitive to conditions created by reclamation practices and natural site factors. Softwood species as a group performed marginally for meeting bond release requirements, but the hardwood species group, growing under current conditions common to traditional post-SMCRA reclamation, did not perform well enough to meet performance standards in most states. Studies have shown that both species groups can survive and grow well on uncompacted mine soils with appropriate chemical properties and free of severe competition (Ashby et al., 1980; Rodrigue et al. 2004). Based on the relatively poor performance of both species groups on these ten operational study sites, it is clear that reclamation must be better tailored towards conditions required for tree growth, and that site-specific selection of species must be made to maximize the potential for bond release and future forest value.

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