FIRST YEAR SEEDLING RESPONSE TO THREE LEVELS OF SILVICULTURAL INPUT ON POST-SMCRA RECLAIMED LANDS[1]

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Abstract. Surface mined lands in the Appalachian coal producing region reclaimed after the passage of the Surface Mining Control and Reclamation Act of 1977 (SMCRA) have been found to have dense ground covers, compacted soil materials, and unfavorable soil chemical properties. To address these concerns three study sites, which had been reclaimed post-SMCRA, were located in Lawrence County, Ohio, Nicholas County, West Virginia, and Wise County, Virginia. At each site, three species assemblages were planted across a gradient of three levels of silvicultural intensity intended to alleviate the previously mentioned problems associated with post-SMCRA mined land. Response to treatment was variable by site with the site in Virginia having the best survival and greatest growth of the three sites. Hardwood species survived better at all sites than white pine or hybrid poplar. Hardwood survival across treatments was 80 and 85% for sites in Virginia and West Virginia respectively, while only 50% in Ohio. Hybrid poplar height and diameter growth were superior to other species with the height growth of this species reaching 126.6cm in the most intensive treatment at the site in Virginia. Hybrid poplar biomass increased from 15.7g to 104.5g from the least intensive to the most intensive silvicultural treatment for the site in Nicholas County, West Virginia. Hybrid poplar's excellent response to silvicultural treatment and adequate survival, especially at the site in Virginia, may give this species an advantage over the others tested in this experiment for reverting post-SMCRA reclaimed mined lands supporting grasses back to forests.

Additional Key Words: compaction, ground cover, fertility, reforestation, native hardwoods, white pine, hybrid poplar, reclamation

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[1] Paper was presented at the 2005 National Meeting of the American Society of Mining and Reclamation, Breckenridge CO, June 19-23 2005. Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

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Proceedings America Society of Mining and Reclamation, 2005 pp 191-211
DOI: 10.21000/JASMR05010191
`https://doi.org/10.21000/JASMR05010191`

Introduction

Surface mining activities conducted after August 3, 1977 are subject to the provisions of Public Law 95-87, the Surface Mining Control and Reclamation Act of 1977 (SMCRA). This law mandates all surface mined lands be reclaimed after mining and sets forth criteria for mine operators to follow in carrying out reclamation practices. Unfortunately, many of these criteria can create adverse conditions for reclamation with trees, and consequently reforestation of surface mined lands has decreased since the passage of SMCRA (Ashby, 1991). These adverse conditions include 1) excessive competing vegetation; 2) soil compaction; and 3) unfavorable soil chemical properties.

Competing vegetation is a direct result of ground covers sown to prevent soil erosion on newly reclaimed surfaces. The most commonly used ground covers include tall fescue (*Festuca arundinacea* Schreb.), clover species (*Trifolium spp.*), and other grasses and legumes. These dense grasses and legumes compete with tree seedlings for light, water and nutrients (Ashby, 1991). On a surface mine in Indiana, Andersen and coworkers (1989) found that black walnut (*Juglans nigra* L.) and northern red oak (*Quercus rubra* L.) survival after seven growing seasons increased from 4% and 1% respectively when planted into an existing dense ground cover to 66% and 48% respectively when planted after ground cover was controlled. Adequate stocking of trees required to meet the specifications of SMCRA (1110 trees ha^{-1}) was attained only when the ground cover was controlled with herbicide. Height growth was also significantly better on the mine site where weeds were controlled. Twelve-year results of this study again showed that height growth was enhanced by weed control (Chaney et al., 1995).

Soil compaction on post-SMCRA reclaimed mined lands is also widespread. Soil compaction in mine soils is usually caused by the passage of large equipment over the soil in an effort to stabilize the soil when returning it to its approximate original contour as required by SMCRA. Soil compaction inhibits root growth of seedlings by increasing bulk density and consequently increasing soil strength, decreasing aeration porosity, and inhibiting the ability of the soil to drain once saturated (Omi, 1985). Tillage treatments can ameliorate the detrimental effects of compaction. Ashby (1997) found that the mean height of 16 different tree species was significantly greater five years after ripping the mine soil to a depth of 1.2m. Another study found that after 12 years, ripping to a depth of 85cm significantly increased the survival, height, and diameter growth of both red oak and black walnut in southern Illinois (Ashby, 1996). Black walnut seedlings growing on a surface mine in southern Illinois were found to have taproot lengths which were 92% and 75% greater in their first and second years of growth, respectively, in ripped versus unripped plots (Philo et al., 1982). This same study found overall rooting depth to be 81% and 58% greater in their first and second years in the ripped versus the unripped plots. Radial root growth was found to be 89% greater in the ripped plots in the second year.

Chemical properties of mine soils are related to the overburden rock type from which these soils were created. In a study of the effect of overburden rock type on survival and growth of pitch x loblolly pine hybrids (*Pinus rigitaeda*), an inverse relationship between soil pH and tree growth was found (Torbert et al., 1990). The rock types evaluated in this study consisted of pure sandstone and pure siltstone as well as mixtures of various amounts of these types. It was noteworthy that pH increased consistently as the proportion of sandstone decreased and as the proportion of siltstone increased. Plant available N and P are low on mine soils. Howard and coworkers (1988) found that mine soils in southwest Virginia had large quantities of P and K, but they suggest that P will likely be deficient even after fertilization due to the high P-fixing capacity of these soils. Another study in southwest Virginia found that compared to native forest soils, mine soils had less total N, and that the forms of N in the mine soils were largely unavailable to plants (Li and Daniels, 1994).

Numerous species of trees have been studied for use in reclamation with varying degrees of success depending on the site conditions. White pine (*Pinus strobus* L.) has been used extensively to reclaim mined land in the east, although with variable success. For example, one study in southwestern Virginia found good survival (58%) and height growth after (3.8m) after 11 years (Torbert et al., 2000) whereas in a study in southeastern Ohio no pines survived after three years (Larson et al., 1995).

Several hardwood species have also been tested for use in reclaiming surface mined lands. Gorman and Skousen (2003) found excellent survival (90 to 100%) of several commercially valuable hardwoods, including red oak, black walnut, black cherry (*Prunus serotina* Ehrh.), yellow poplar (*Liriodendron tulipifera* L.), and white ash (*Fraxinus americana* L.) on a reclaimed mountain top removal mine in West Virginia when weed control and tillage were employed. A study in southwestern Virginia reported survival rates of 57% for chestnut oak (*Quercus prinus* L.), 54% for yellow poplar, and 91% for white ash in plots where weeds were controlled chemically (Torbert et al. 1985).

The purpose of this study was to evaluate the impact of silvicultural treatments designed to ameliorate growth limiting conditions on survival and growth of a variety of tree species planted on post-SMCRA reclaimed mined land in the Appalachian coal producing region of the eastern United States.

Methods and Materials

Study design

The study used a 3x3 factorial combination of treatments across three sites in a randomized complete block design to investigate the effects of silvicultural treatment, species assemblage, and site conditions on seedling survival and growth. This design was replicated with three blocks at each of three study sites. The three levels of silvicultural treatment were:

1) Low intensity – weed control only (WC);
2) Medium intensity – weed control plus tillage to alleviate soil compaction (WC+T); and
3) High intensity – weed control and tillage plus fertilization to amend soil chemical properties (WC+T+F).

The tree species assemblages used were:

1) White pine;
2) Hybrid poplar (*Populus trichocarpa* L. (Torr. & Gray ex Hook.) x *Populus deltoides* (Bartr. ex Marsh.) hybrid 52-225), and;
3) Native hardwood mix.

All trees were planted at a 2.4m x 3.0m spacing giving a final planting density of 1,345 trees ha^{-1}. White pine and hybrid poplar were planted in pure stands; while a mixture of hardwood species were planted at each site. The mixture varied by site in order to approximate the premining forest condition found in adjacent undisturbed forest (Table 1). In addition to commercial hardwood species, a combination of three nurse tree species were planted to provide early wildlife habitat and to more closely resemble the species diversity found in the native hardwood mixture (Burger and Zipper, 2002).

Table 1. Species composition and percentage of each species for the mixed hardwood plots at the three study sites.

Ohio	%	West Virginia	%	Virginia	%
Commercial Hardwoods					
Northern Red Oak (*Quercus rubra* L.)	9.6	Northern Red Oak	15.3	Northern Red Oak	10.9
Tulip Poplar (*Liriodendron tulipifera* L.)	9.6	Tulip Poplar	15.3	Tulip Poplar	10.9
Sugar Maple (*Acer saccharum* L.)	9.6	Sugar Maple	15.3	Sugar Maple	10.9
Black Oak (*Quercus velutina* Lam.)	9.6	Red Maple (*Acer rubrum* L.)	15.3	Bitternut Hickory	10.9
Chestnut Oak (*Quercus prinus* L.)	19.2	White Ash (*Fraxinus americana* L.)	15.3	White Oak (*Quercus alba* L.)	21.9
Bitternut Hickory (*Carya cordiformis* [Wengenh.] K.Koch)	9.6			White Ash	10.9
Scarlet Oak (*Quercus coccinea* Muenchh.)	9.6				
Nurse Tree Species					
Redbud (*Cercis canadensis* L.)	7.7	Redbud	7.8	Redbud	7.8
Flowering Dogwood (*Cornus florida* L.)	7.7	Flowering Dogwood	7.8	Flowering Dogwood	7.8
Wash. Hawthorn (*Cretaegus phaenopyrum*)	7.7	Wash. Hawthorn	7.8	Wash. Hawthorn	7.8

Study sites were located in Lawrence County Ohio, Nicholas County West Virginia, and Wise County Virginia on land surface mined for coal and subsequently reclaimed according to SMCRA regulations (Fig. 1). The post-mining land use at all sites was hay-land pasture and a dense vegetative cover composed of grasses and legumes existed prior to study establishment. The site in Lawrence County, Ohio had topsoil replaced to varying depths, which ranged from 5 to 51cm across the site. Both the topsoil and the spoil had fine textures and low coarse fragment percentages (Tables 2 and 3). The topsoil had a lower pH and electrical conductivity than the spoil that was derived from siltstone material. The site had been reclaimed for at least ten years and had supported a dense cover of predominantly tall fescue and sericea lespedeza (*Lespedeza cuneata* (Dum.-Cours.) G.Don) prior to study establishment.

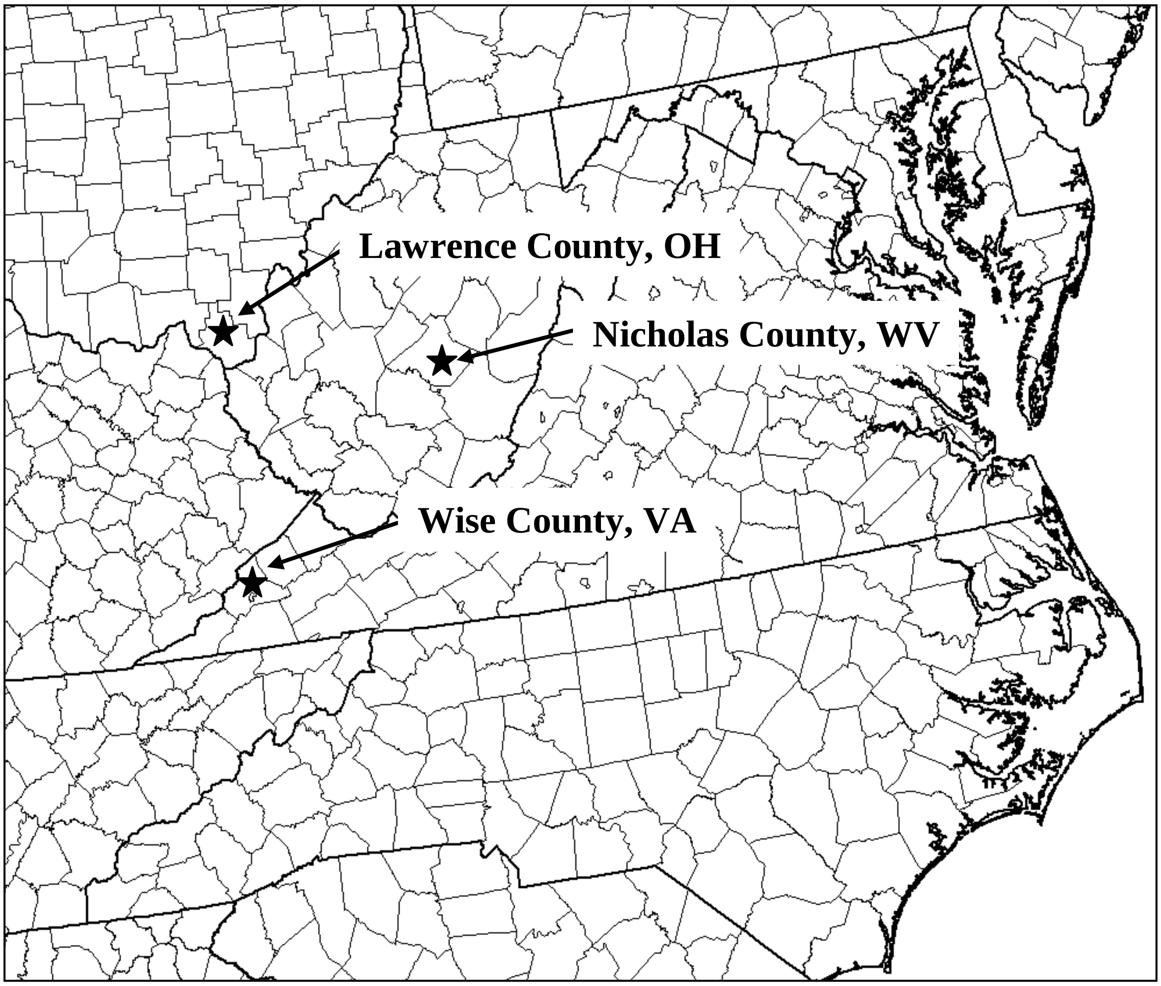

Figure 1. Geographic location of study sites.

The Nicholas County, West Virginia site did not have topsoil replaced and the spoil at this site was derived from shale material. The site had coarse soil textures and high coarse fragment contents (50-60%) throughout the profile (Tables 2 and 3). The site was used for grazing prior to study establishment with the dominant grass species being tall fescue and had been reclaimed for at least ten years.

The site in Wise County, Virginia was derived from sandstone rocks and soil textures ranged from loam to sandy loam. This site had topsoil returned to the surface throughout the plots that ranged in thickness from 0 to 47cm. This site also had high coarse fragment percentages; however, the spoil typically had more coarse fragments than the topsoil (Tables 2 and 3). The blocks at this site had been reclaimed for less than five years with one block having been reclaimed the spring before study establishment. The newly reclaimed block was seeded to an annual ground cover, while the other two sites were dominated by tall fescue and sweet clover.

Plots were blocked within each site based on soil properties (Tables 2 and 3). Nine 0.25ha plots were established in each of the three blocks at each site. Plots were laid out to be as contiguous as possible within each block, while still maintaining uniform soil properties. Slopes in all plots were less than 15%.

The weed control treatment used herbicide to reduce existing herbaceous vegetation. In August 2003 a broadcast treatment of glyphosate herbicide was applied at a rate of 9.35l ha^{-1} (41% active ingredient). Following the glyphosate treatment, a pre-emergent herbicide containing pendimethalin was applied after tree planting in April 2004 at a rate of 4.92l ha^{-1} (38.7% active ingredient) to control germinating grasses. Spot applications of glyphosate were applied around each seedling in July 2004 to control competition at all study blocks except for one block at the Virginia site where no competition was present. Seedlings were shielded from herbicide drift during this application.

The tillage treatment employed was ripping. The equipment used to install tillage treatments varied by site depending on local equipment availability; however, the same equipment was used within individual blocks. Variations in the tillage treatment included: single shank only, single shank with coulters creating beds, and multiple shanks resulting in tillage of the entire plot. The depth of ripping was set between 61 and 91cm. The plots were treated prior to planting in April 2004.

Fertilizer was applied to the designated plots in late May 2004. A banded application of 272$kgha^{-1}$ of diammonium phosphate added 49.0$kgha^{-1}$ N and 55.1$kgha^{-1}$ P. Muriate of potash and a micronutrient mix were applied around the base of each seedling at the following rates: 91$kgha^{-1}$ of muriate of potash that added 46.8$kgha^{-1}$ K; and 20$kgha^{-1}$ of a micronutrient mix that added 1.8$kgha^{-1}$ S, 0.2$kgha^{-1}$ B, 0.2$kgha^{-1}$ Cu, 0.8$kgha^{-1}$ Mn, and 4.0$kgha^{-1}$ Zn.

Survival and growth data collection

A 20m x 20m measurement plot was established in the center of each 0.25ha treatment plot, within which all trees were assessed for survival, height growth and ground line diameter growth. Initial height (to the estimated base of the terminal bud) and ground line diameter were assessed in May 2004 shortly after bud break. First year survival and growth were determined following measurement in late August of 2004.

Hybrid poplar biomass measurements

Destructive sampling was used to determine above and below ground biomass allocation in the hybrid poplar plots at the site in Nicholas County, West Virginia. Three randomly selected trees located outside the interior measurement plot were harvested in each plot in mid September for plant biomass determinations. Trees were cut off at the ground line and leaves were separated from the stems. The entire root system of each tree was carefully excavated from the soil and washed gently with water to remove soil adhering to the roots. Roots were stored at 1 to 2°C in sealed plastic bags with a moist paper towel for a period of up to four weeks during which time the roots were separated into coarse (>0.5mm) and fine (<0.5mm) root fractions. All tissue samples were dried at 65°C for a minimum of 72 hours and weighed.

Table 2. Chemical and physical properties for 0 to 10cm depth of the topsoil of study blocks at research sites in Lawrence County, OH and Wise County, VA, and of the spoil material in Nicholas County, WV.

Site	Block	pH	Electrical Conductivity (dSm^{-1})	CEC (cmol$_c$ kg^{-1})	NaHCO$_3$ Extractable P (mgkg^{-1})	Total N (gkg^{-1})	Coarse Fragments (%)				Texture	Bulk Density (gcm-3)
							Total	Sandstone	Siltstone	Shale		
OH[†]	1	4.89	0.06	9.26	10.3	1.25	6.4	14.44	85.56	0.00	L[*]	1.53
OH[†]	2	5.19	0.11	7.69	7.69	1.14	6.96	27.22	61.67	0.00	L	1.44
OH[†]	3	6.05	0.13	9.05	5.38	1.06	9.86	27.22	72.78	0.00	L	1.40
Mean		5.38	0.10	8.67	7.79	1.15	7.74	22.96	73.34	0.00	L	1.46
VA[†]	1	4.75	0.18	5.46	9.98	0.58	32.36	72.78	15.00	0.00	L	1.48
VA[†]	2	6.3	0.28	6.57	10.07	0.91	41.06	46.67	31.11	0.00	L	1.87
VA[†]	3	6.43	0.38	5.21	13.75	0.53	51.65	65.00	35.00	0.00	L/SL	1.76
Mean		5.83	0.28	5.75	11.27	0.67	41.69	61.48	27.04	0.00	L	1.70
WV[††]	1	5.91	0.21	8.81	20.13	2.78	54.29	9.44	13.89	76.67	SL	1.66
WV[††]	2	5.72	0.22	8.37	20.81	2.58	55.26	7.22	11.67	81.11	SL	1.71
WV[††]	3	5.52	0.21	7.85	18.03	2.81	46.21	10.56	15.00	73.33	SL	1.67
Mean		5.72	0.21	8.34	19.66	2.72	51.92	9.07	13.52	77.04	SL	1.68

[†] Topsoils in OH and VA were comprised of material replaced specifically as topsoil or topsoil substitute.

[††] Topsoil in WV was the upper 10cm of soil and is the same material that comprises the subsoil layer.

[*] L=loam; SL=sandy loam

Table 3. Chemical and physical properties for spoil materials underlying the topsoil of study blocks at research sites in Lawrence County, OH and Wise County, VA, and of the 10 to 30cm sampling depth of the spoil material in Nicholas County, WV.

Site	Block	pH	Electrical Conductivity (dSm^{-1})	CEC (cmol$_c$ kg^{-1})	NaHCO$_3$ Extractable P (mgkg^{-1})	Total N (gkg^{-1})	Coarse Fragments (%)				Texture	Bulk Density (gcm-3)[**]
							Total	Sandstone	Siltstone	Shale		
OH[†]	1	6.86	0.26	16.21	0	0.48	25.41	18.89	80	1.11	SiCL	1.70
OH[†]	2	6.15	0.61	13.12	0.84	0.52	18.01	21.67	73.89	0	L	1.73
OH[†]	3	6.91	0.53	14.08	0.32	0.43	16.36	8.89	91.11	0	SiCL	1.66
Mean		6.64	0.47	14.47	0.39	0.48	19.93	16.48	81.67	0.37	SiCL	1.70
VA[†]	1	6.77	0.21	6.02	3.38	0.60	50.27	81.43	18.57	0	SL	1.74
VA[†]	2	7.55	0.28	7.46	2.94	0.87	63.25	20	68.89	0	SL	-
VA[†]	3	6.37	0.26	4.35	2.78	0.65	56.57	66.25	33.75	0	SL	-
Mean		6.90	0.25	5.94	3.03	0.71	56.70	55.89	40.40	0.00	SL	1.74
WV[††]	1	6.72	0.1	6.62	7.13	1.20	59.21	10.56	10	67.22	SL	-
WV[††]	2	6.03	0.12	5.89	5.94	1.01	61.56	6.67	12.22	73.11	SL	-
WV[††]	3	5.87	0.1	5.85	3.68	1.00	53	12.22	17.78	59	L/SL	-
Mean		6.21	0.11	6.12	5.58	1.07	57.92	9.82	13.33	66.44	SL	-

[†] Subsurface samples in OH and VA were collected from spoil material located directly below the oxidized material at the surface that was of variable thickness.

[††] Subsurface samples in WV were collected from 10 to 30cm of depth, as this layer was the same material that comprised the topsoil layer.

[*] L=loam; SiCL=silty clay loam; SL=sandy loam

[**] Spoil bulk densities were not measured in all blocks in VA, and in WV were assumed to be the same as the 0-10cm dept

Data Analysis

Analysis of variance was used to analyze survival and growth data for differences in survival percentage, height growth, and diameter growth as a 3x3x3 factorial random complete block design having three species assemblages, three sites, and three silvicultural treatments (Table 4). A separate analysis of variance was done for each site if interaction terms containing site were significant in the overall model. Likewise, if the species by treatment interaction was significant after analyzing by site, analysis of variance was done by species and by treatment to perform mean separation procedures. Seedling survival was expressed as a percentage of the trees planted and these data were transformed using the arcsine transformation. The growth measures that showed non-normality or heteroscedasticity and failed to meet the assumptions of the analysis of variance were transformed using the natural log function prior to analysis of variance and subsequent mean separation procedures (Gomez and Gomez, 1984).

Hybrid poplar biomass data were analyzed for differences among the silvicultural treatments. Arcsine transformation was used to transform percentage data prior to analysis of variance and any non-normal or heteroscedastic data were transformed using either the inverse or natural logarithm transformation prior to analysis (Gomez and Gomez, 1984). Non-normal and heteroscedastic data were transformed using the inverse function prior to analysis of variance.

Mean separation was conducted using Tukey's HSD with significance set at $P<0.05$ for all comparisons. If interaction terms were not significant, only main effect means were compared. SAS version 8.2 (SAS Institute Inc., Cary, NC 2001) was used for all statistical analyses.

Results

The site by treatment and site by species group interaction terms were significant for all response variables measured (Table 4). Therefore, because each site was established as a random complete block experiment with three replications, the results will be presented separately for each location. This enables us to focus on the interaction between species group and silvicultural treatment at each of the three study locations, which we felt were the more important aspects of the results.

Survival

The species by treatment interaction was not significant for any site (Table 4). Treatment main effects in Ohio (OH) show that weed control plus tillage plus fertilization (WC+T+F) significantly decreased survival to 14% compared to weed control plus tillage (WC+T) and weed control only (WC), which had similar survival rates at 49% and 51% respectively (Table 5). At the West Virginia (WV) site, survival in WC+T was significantly higher than either of the other treatments. Silvicultural treatments had no effect on survival in Virginia (VA). The mean survival across species and silvicultural treatments was notably higher in VA than at the other sites, though site means were not separated.

The hardwood species group had the highest mean survival at all sites (Table 5) and was significantly higher than all other species at all three sites except in OH where hardwood survival was no different from hybrid poplar. White pine generally had the lowest survival at all three locations ranging from 27% to 58%. Survival of hybrid poplar was low in OH and WV, at 37 and 41% respectively, but as with the other species groups was higher in VA averaging 72% (Table 5).

Table 4. Analysis of variance results for survival and growth parameters for research sites in Lawrence County, OH, Nicholas County, WV, and Wise County, VA.

Site and Source	Degrees of Freedom	Variable (Pr>F) Survival	Height Growth	Diameter Growth
All Sites				
Block	2	0.0057	0.0076	0.0812
Site	2	<0.0001	<0.0001	0.0004
Treatment	2	<0.0001	<0.0001	<0.0001
Site*Treatment	4	0.0097	0.0003	0.0036
Species	2	<0.0001	<0.0001	<0.0001
Site*Species	4	0.0332	<0.0001	0.0009
Treatment*Species	4	0.3567	<0.0001	<0.0001
Site*Treatment*Species	8	0.3367	<0.0001	0.1146
Model	28	<0.0001	<0.0001	<0.0001
Error†	52(51)			
Total†	80(79)			
Ohio				
Block	2	0.1730	0.0354	0.1340
Treatment	2	0.0005	0.5026	0.6628
Species	2	0.0197	<0.0001	<0.0001
Treatment*Species	4	0.3072	0.6724	0.1790
Model	10	0.0038	<0.0001	<0.0001
Error†	16 (15)			
Total†	26 (25)			
West Virginia				
Block	2	0.4873	0.0180	0.0713
Treatment	2	<0.0001	<0.0001	<0.0001
Species	2	<0.0001	<0.0001	<0.0001
Treatment*Species	4	0.1384	<0.0001	0.0003
Model	10	<0.0001	<0.0001	<0.0001
Error†	16			
Total†	26			
Virginia				
Block	2	0.0164	0.6402	0.9342
Treatment	2	0.3422	<0.0001	<0.0001
Species	2	0.0006	<0.0001	<0.0001
Treatment*Species	4	0.4849	<0.0001	<0.0001
Model	10	0.0060	<0.0001	<0.0001
Error†	16			
Total†	26			

†Degrees of freedom in parentheses are for height and diameter growth variables. Zero survival in one study block caused the loss of one degree of freedom from these growth variables.

Table 5. Survival percentage for three species groups planted on post-SMCRA reclaimed surface mined lands in Lawrence County, OH, Nicholas County, WV, and Wise County, VA as affected by silvicultural treatments.

Site and treatment	Species Group HW	HP	WP	Treatment Mean
Ohio				
WC	60	49	45	51x**
WC+T	72	45	29	49x
WC+T+F	18	17	6	14y
Species Mean	50A*	37AB	27B	38
West Virginia				
WC	78	32	41	51x
WC+T	94	62	50	69y
WC+T+F	68	27	33	43x
Species Mean	80A	41B	41B	54
Virginia				
WC	81	79	53	71x
WC+T	90	70	70	77x
WC+T+F	84	67	50	67x
Species Mean	85A	72B	58B	72

*A,B,C–For each site, values within rows with the same letter are not significantly different at *P*<0.05.

**x, y, z – For each site, values within columns with the same letter are not significantly different at *P*<0.05.

Height Growth

Analysis by site revealed that the species by treatment interaction was not significant in OH and that there were no treatment effects at this site (Table 4). At all sites, hybrid poplar grew significantly more than hardwood and white pine, which were not different. Height growth of hybrid poplar was several times higher than in hardwood and white pine in OH (45.6cm versus –2.3cm and 6.0cm respectively). Seedlings in the hardwood group often died back, thus they were often shorter at the end of the growing season than at the start, hence negative height growth was observed for all treatments at this site for the hardwood group (Table 6).

At WV, the species by silvicultural treatment interaction was significant (Table 4) and height growth for hardwood was greater in WC+T+F than in WC (Table 6). Height growth of hybrid poplar in WC (22.4cm) was significantly less than in both of the other treatments (60.2cm for WC+T and 57.6cm for WC+T+F). Hybrid poplar at this site grew significantly more than hardwood and white pine in all treatments. In the WC treatment, white pine also had significantly more height growth than hardwood (5.5cm versus –1.4cm).

Table 6. Average height growth (cm) for three species groups planted on post-SMCRA reclaimed surface mined lands in Lawrence County, OH, Nicholas County, WV, and Wise County, VA as affected by silvicultural treatments.

Site and treatment	Species Group			Treatment Mean
	HW	HP	WP	
Ohio				
WC	-1.0	35.8	5.2	13.3x**
WC+T	-3.7	50.3	5.4	17.4x
WC+T+F	-2.3	50.8	7.9	20.2x
Species Mean	-2.3A*	45.6B	6.0A	16.8
West Virginia				
WC	-1.4A x	22.4B x	5.5C x	8.8
WC+T	3.2A xy	60.2B y	8.9A x	24.1
WC+T+F	7.7Ay	57.6B y	5.8A x	23.7
Species Mean	3.2	46.7	6.7	18.9
Virginia				
WC	3.7A x	40.9B x	6.0A x	16.9
WC+T	3.9A x	65.4B x	5.9A x	25.1
WC+T+F	7.9A y	126.6B y	5.5A x	46.7
Species Mean	5.2	77.6	5.8	29.5

[*] a, b, c –For each site, values within rows with the same letter are not significantly different at *P*<0.05.

[**] x, y, z – For each site, values within columns with the same letter are not significantly different at *P*<0.05.

In VA, there was also significant treatment by species interaction (Table 4) and height growth was greater in WC+T+F than in the other treatments for both hardwood and hybrid poplar (Table 6). The differences in height growth were more pronounced for hybrid poplar (126.6cm in WC+T+F versus 40.9 and 65.4cm for WC and WC+T respectively) (Table 6).

Diameter Growth

There was no interaction between species and silvicultural treatment nor were there anysilvicultural treatment effects on diameter growth at the OH site (Table 4). However, diameter growth of hybrid poplar (5.7mm) was significantly greater than diameter growth in hardwood or white pine, which both averaged 0.7mm.

A significant interaction between species group and silvicultural treatment occurred in WV (Table 4). At this site, diameter growth of hybrid poplar was greater than diameter growth of either the hardwood or white pine species groups in all silvicultural treatments (Table 7). Diameter growth of hybrid poplar also responded to silvicultural treatment, increasing from

3.1mm in WC to 7.0mm in WC+T to 7.5mm in WC+T+F. In contrast, diameter growth of both hardwood and white pine did not respond to silvicultural treatment. Diameter growth of hardwood was 0.9mm in WC and only 1.8mm in WC+T+F, while diameter growth of white pine was only 0.5mm and 0.9mm in these two treatments respectively.

A similar pattern among species and treatments occurred for diameter growth in VA (Table 7), which also had a significant species by silvicultural treatment interaction (Table 4). Diameter growth of hybrid poplar was greater than the diameter growth of both hardwood and white pine in all treatments. As in WV, diameter growth of hardwood and white pine was not affected by silvicultural treatment, ranging only from 0.8mm to 2.1mm and from 0.6mm to 0.7mm in the two species respectively. Diameter growth of the hybrid poplar was significantly affected by silvicultural treatment increasing from 4.9mm in WC to 7.0mm in WC+T to 13.9mm in WC+T+F.

Hybrid poplar biomass

Total plant biomass of hybrid poplar at the site in WV increased significantly (P=0.0002) with the intensity of silvicultural input (Fig. 2). Total plant biomass increased from 15.7g in WC to 45.9g in WC+T to 104.5g in WC+T+F. Root, stem, and foliage biomass also increased significantly with the level of silvicultural intensity (Fig. 2). The percentage of fine roots (<0.5mm) was the same for the WC+T+F and WC+T treatments (23%) while the WC plots had a much higher fine root percentage (54%), which was significantly different from the other two treatments. Additionally, the root to shoot ratios were not significantly different between WC+T and WC+T+F (0.31 and 0.37 respectively), but both were significantly higher than that of the WC treatment (0.08).

Discussion

The results of this study point to the fact that there is likely no universal prescription for good establishment and first year growth of the species used in this study as numerous interactions existed between the sites, treatments, and species assemblages. The results of this study fit well with other studies using similar species and treatments on post-SMCRA reclaimed mined lands. For example, a study conducted on three surface mines in West Virginia using species similar to those in the current study found that in plots receiving similar treatments to the WC+T+F treatment in our study, the same hybrid poplar clone averaged 1.0m in total height after one year and average first year survival for this same species across all three sites was found to be 79%(McGill et al., 2004). Additionally, these authors found excellent survival (>90%) for the two hardwood species used (white ash and black cherry) and found low survival for white pine (48%) at the one site at which this species was planted. On a site in northern West Virginia, red oak, black cherry, black walnut, white ash, and yellow poplar were found to have excellent survival (95 to 100% after one year) where treated with ground cover control through mowing and tillage through ripping (Gorman and Skousen, 2003). At our sites, hardwoods had the best survival of all species and excluding the site in OH, survival in the WC and WC+T treatments ranged from 78 to 90% after one year.

Table 7. Average diameter growth (mm) for three species groups planted on post-SMCRA reclaimed surface mined lands in Lawrence County, OH, Nicholas County, WV, and Wise County, VA as affected by silvicultural treatments.

Site and	Species Group			Treatment
treatment	HW	HP	WP	Mean
Ohio				
WC	0.9	4.1	0.9	2.0x**
WC+T	0.8	5.5	0.5	2.3x
WC+T+F	0.3	7.4	0.7	3.1x
Species Mean	0.7A*	5.7B	0.7A	2.4
West Virginia				
WC	0.9A x	3.1B x	0.5C x	1.5
WC+T	1.4A x	7.0B y	0.7A x	3.0
WC+T+F	1.8A x	7.5B y	0.9A x	3.4
Species Mean	1.4	5.9	0.7	2.6
Virginia				
WC	0.8A x	4.9B x	0.6A x	2.1
WC+T	1.4A x	7.0B x	0.6A x	3.0
WC+T+F	2.1A x	13.9B y	0.7A x	5.6
Species Mean	1.4	8.6	0.6	3.6

*A,B,C –For each site, values within rows with the same letter are not significantly different at $P<0.05$.

**x, y, z – For each site, values within columns with the same letter are not significantly different at $P<0.05$.

Overall survival was lowest in OH with white pine having the lowest survival of the three species assemblages at this site. Larson et al. (1995) found white pine to survive and grow poorly on sites in this geographic area with the near alkaline and fine texture spoil materials common to the area. Similar results were found by Kost and coworkers (1998) for white pine planted in graded cast overburden in southeastern OH. Another reason for poor survival and growth of white pine in OH would be the fact that white pine performs best on well drained soils within its native range (Wendel and Smith, 1990) and the soils in OH were found to have fine textures, no soil structure, and many areas with hydrophytic vegetation indicating anaerobic conditions and poor drainage.

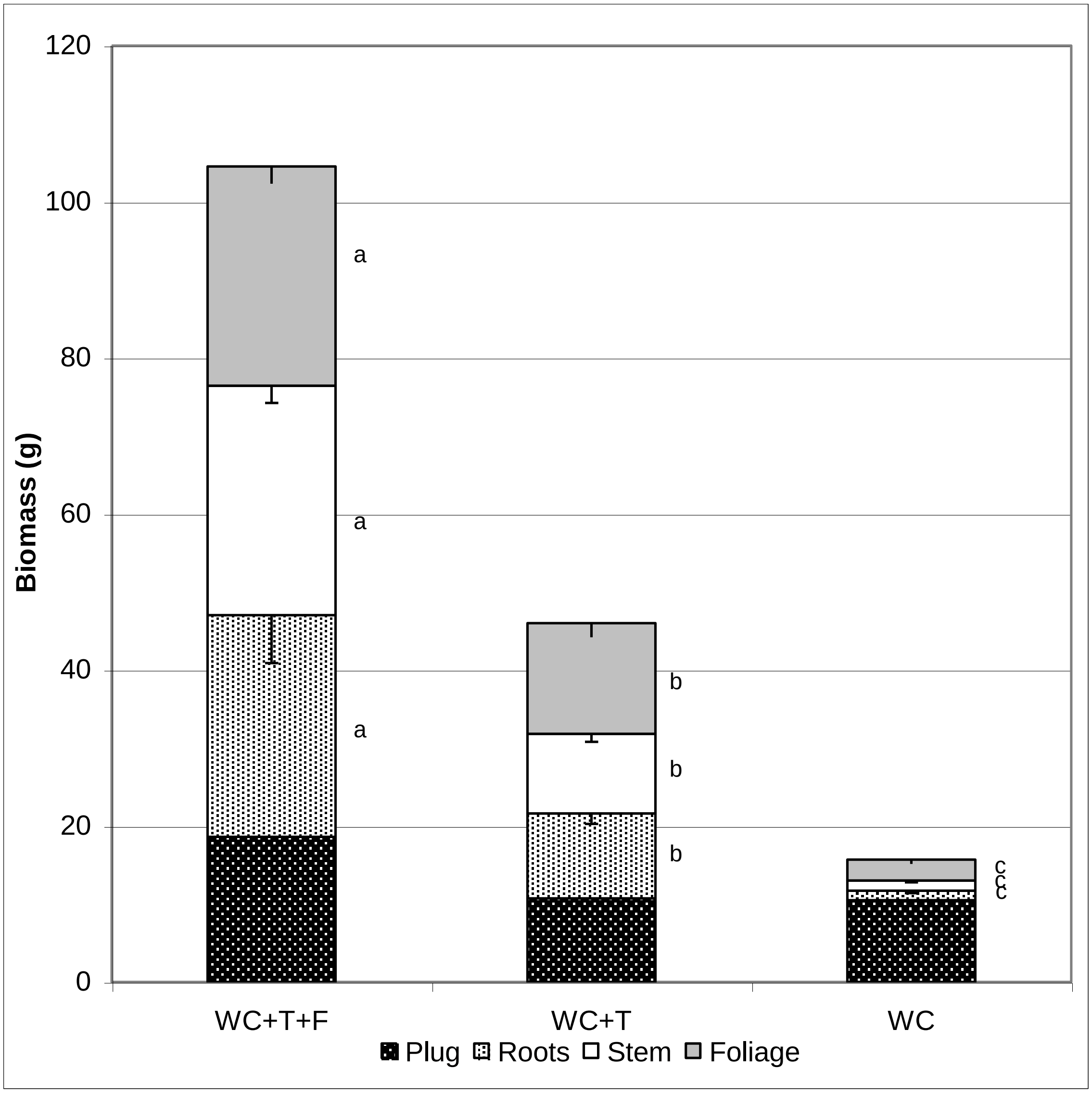

Figure 2. Hybrid poplar biomass by plant part and treatment for the study site in Nicholas County, WV. Letters beside segments indicate significant differences at the $P<0.05$ level between treatments for that particular segment.

In OH, WC+T+F significantly decreased survival below that of the WC only treatment, which did not occur at the other two sites though mean survival was lower in WC+T+F than in either of the other treatments at the other two sites. Two hypotheses exist for decreased survival in the WC+T+F treatment: 1) Fertilization stimulated the competing vegetation (Ramsey et al., 2001), and/or 2) A salt effect was created by the fertilizer leading to moisture stress in the trees, as diammonium phosphate and muriate of potash fertilizers are considered to pose moderate and high salt hazards respectively (Brady and Weil, 2002). For a detailed review of salt effects in forest trees see Allen and coworkers (1994). Such an effect leading to decreased tree survival was postulated by van den Driessche and coworkers (2003) for aspen seedlings. In OH, a combination of these two hypotheses would be more likely as despite uniform herbicide applications at all sites, OH was observed to have much more competing vegetation by the end of the growing season than either of the other sites. Additionally, the spoils at this site, though covered with topsoil material, were still generally within the rooting zone of the trees. This would be especially true in WC+T and WC+T+F where tillage brought this material closer to the surface. The spoils at this site were found to be near alkaline and to have a much higher cation exchange capacity relative to the other sites (Tables 2 and 3). Both the pH and electrical conductivity at this site were within ranges (pH>6.0 and electrical conductivity>0.05dS m^{-1} respectively) reported by Torbert and coworkers (1994) as negatively affecting white pine growth. Electrical conductivity in both surface and subsurface layers at the sites in WV and VA had values less than 0.05dS m^{-1}. In addition to this, the loam to sandy loam textures at these sites could have allowed excess salts to leach out of the rooting zone faster than what would be expected in the finer textured structureless spoils in OH given that coarse textured soils generally have more water movement through them and less colloidal surfaces for salts to adhere to.

In addition to added weed control as a result of tillage, tillage has been shown to reduce bulk density and consequently increase survival and growth of trees on reclaimed surface mines (Ashby, 1996; Torbert and Burger, 1996). Tillage in this study produced mixed results in terms of survival and growth response. In OH, WC+T did not produce a significant response compared to the WC treatment. As previously noted, the tillage treatment would have brought the roots into contact with the spoil, which would have been detrimental to survival and growth. The tillage treatment was also carried out at this site when the soils were very wet. Given that the soils at this site are fine textured, that the spoils were only 20% coarse fragments, and that more coarse fragments would tend to aid in loosening the soil during ripping, it is possible that the reason for the lack of response in OH is that the tillage treatment failed to sufficiently loosen the soil at this site. Further evidence that an ineffective tillage treatment would not lead to increased survival or growth in OH would come from Shukla and coworkers (2004) who found soil bulk density to be the most discriminating soil quality indicator of all the principle components measured in a study of two reclaimed mined sites in Jackson and Vinton counties in southeastern OH and that failure to ameliorate this condition would result in decreased site quality.

There was a notable response to WC+T for hybrid poplar in WV in terms of survival, growth, and biomass measures indicating that soil compaction is likely a limiting factor for good growth at this site. Survival and growth of white pine were also improved as a result of WC+T at this site. The increase in hybrid poplar height growth was nearly three fold and diameter growth nearly doubled as a result of WC+T. Additionally, WC+T produced nearly three times more total plant biomass for hybrid poplar compared to the WC treatment. The higher fine root percentage in the WC treatment combined with considerably less total root biomass compared to WC+T and WC+T+F is likely due to the fact that roots greater than 0.5mm were not able to penetrate the soil as effectively in the untilled treatment as roots can only enter soil pores with a diameter greater than that of the root (Kozlowski, 1999). This is further evidenced by the extremely low total plant, root, and shoot biomass found in the WC treatment compared to the other treatments. An inverse relationship between soil density and several plant growth measures have been found by researchers, for example, Foil and Ralston (1967) found such a relationship between bulk density with root length and root weight for loblolly pine. Hatchell (1970) found a similar relationship between bulk density with shoot weight and root weight for the same species. Zisa and coworkers (1980) found an inverse relationship between bulk density and depth of root penetration for three pine species.

The sites in VA and WV were both characterized by coarse textured spoils and high coarse fragment contents (Tables 2 and 3). The primary differences between these two sites were rock type, topsoil replacement, and average age since reclamation. The site in VA had similar soil textures and bulk densities to the WV site, but did not have a significant response to WC+T. However, mean survival and mean growth for all measures across species were higher in WC+T than in WC only at the VA site. One explanation for the lack of response to WC+T in VA compared to the dramatic response in WV would be the improved water holding capacity in the surface soil in VA with a loam texture and an average coarse fragment content of 41.69% versus the WV soils, which had a sandy loam texture and a 51.92% coarse fragment content. A study comparing overburden rock types in southwest Virginia found that oxidized sandstone spoils (such as those in VA for our study) had lower coarse fragment contents, and consequently had more water retention capacity on a whole soil basis than finer textured siltstone spoils (Torbert et al., 1990).

Looking at survival differences between these two sites, it can be seen that survival in VA was better than that in WV regardless of species or treatment. The oxidized sandstone topsoil present at the Virginia site has been shown to be a preferable growth medium for trees (Torbert et al., 1990; Preve et al., 1984; Torbert et al., 1991). The response to WC+T+F was exceptional for hybrid poplar in VA where total heights averaged 126.6cm. The next closest total height was also in VA in WC+T at 65.4cm followed by WC+T in WV at 60.2cm. This species has been shown to be very responsive to fertilization with N in combination with P when soil fertility levels are low (van den Driessche, 1999; Brown and van den Driessche, 2005) as was the case in VA where spoils from the same geologic formation have been shown to be inherently low in plant available N (Li and Daniels, 1994) and have high P fixing capacities (Howard et al., 1988). Additionally, better weed control on the younger spoils in VA where the seed pool for competing vegetation may have been smaller could have resulted in better survival and growth at this site compared to WV. Soil N and P levels were much higher in the surface layer in WV than in the subsurface layer at the same site and higher than the topsoils or spoils in VA and OH. This may be evidence that the site was fertilized to maintain the lush grass cover for the grazing animals that occupied the site prior to study establishment, making weed control more difficult in the WC+T+F plots by adding nutrients in excess of what the trees likely needed. Fertilization of this site prior to study establishment could also explain the lack of a significant height or diameter growth response due to fertilization in addition to tillage in WV, especially for the site demanding poplars. Stanturf and coworkers (2001) have found that hybrid poplar do not always respond to fertilization on native soils with high levels of inherent fertility. Hybrid poplar at this site did, however, have significantly higher root, stem, foliage, and total plant biomass in the fertilized plots versus the other two treatments.

Conclusions

Several conclusions can be drawn from the results of this investigation including:

1. White pine and hardwood species grew little over the course of the first growing season. This could translate into a need for continued weed control to ensure the trees do not succumb to the competing vegetation.
2. Hardwood species had excellent survival in WV and VA, and better survival than the other species used in OH, while white pine had the poorest survival of all species at all sites.

3. Weed control plus tillage may be the optimum treatment for establishment of hardwoods and white pine, as any increased growth resulting from fertilization may not offset the decreased survival that accompanied fertilization.
4. Sites with sandstone derived topsoil as a rooting medium would seem to be very suitable for tree survival and growth, while shale derived spoils appear to be less suitable with the treatments and species used. For fine textured siltstone derived topsoils and alkaline spoils other treatments and/or species may be needed to ensure good establishment and growth of forest stands.
5. Hybrid poplar appears to have good potential for reverting post-SMCRA mined lands reclaimed to grasses back to forests as this species had good growth with 50 to 65cm of height growth in one year in WC+T at all sites and excellent growth in WC+T+F in VA (126.6cm). This good growth coupled with survival percentages that may be adequate to ensure that without further weed control, an adequately stocked stand could develop, gives this species an advantage over the other species used in this study. Additionally, though height and diameter growth were not statistically different for hybrid poplar in WC+T and WC+T+F in WV, biomass responded significantly to each level of silvicultural input..

Acknowledgements

The authors acknowledge the U.S. Department of Energy for the financial support of this research (grant number: DE-FC26-02NT41619). The in kind support of Plum Creek Timber Company, Inc., Mead Westvaco, The Nature Conservancy, Penn Virginia Resource Partners, L.P., and Williams Forestry and Associates is also gratefully acknowledged. Thanks also to Andy Jones for the much needed help with the installation of the study and field data collection.

References

Allen, J.A., J.L. Chambers, and M. Stine. 1994. Prospects for increasing the salt tolerance of forest trees: a review. Tree Physiology. 14:843-853. http://dx.doi.org/10.1093/treephys/14.7-8-9.843 PMid:14967653.

Andersen, C.P., B.H. Bussler, W.R. Chaney, P.O. Pope, and W.R. Byrnes. 1989. Concurrent establishment of ground cover and hardwood trees on reclaimed mined land and unmined reference sites. Forest Ecology and Management. 28:81-99. http://dx.doi.org/10.1016/0378-1127(89)90062-5.

Ashby, W.C. 1991. Surface mine tree planting in the Midwest pre- and post-Public Law 95-87. *In* Oaks, W., and J. Bowden (ed.) Technologies for Success. Proceedings American Society for Surface Mining and Reclamation Vol. 2., May 14-17. Durango, CO. American Society for Surface Mining and Reclamation, Lexington, KY.
https://doi.org/10.21000/JASMR91020617

Ashby, W.C. 1996. Red oak and black walnut growth increased with mine soil ripping. International Journal of Surface Mining and Reclamation. 10(3):113-116. http://dx.doi.org/10.1080/09208119608964813.

Ashby, W.C. 1997. Soil ripping and herbicides enhance tree and shrub restoration on stripmines. Restoration Ecology. 5(2):169-177. http://dx.doi.org/10.1046/j.1526-100X.1997.09720.x.

Brady, N.C. and R.R. Weil. 2002. *The Nature and Properties of Soils*. 13th ed. Prentice Hall, Upper Saddle River.

Brown, K.R. and R. van den Driessche. 2005. Effects of nitrogen and phosphorus fertilization on the growth and nutrition of hybrid poplars on Vancouver Island. New Forests. 29:89-104. http://dx.doi.org/10.1007/s11056-004-5418-4.

Burger, J.A. and C.E. Zipper. 2002. How to restore forests on surface-mined land. Va. Coop. Exten. Serv. Publ. 460-123. Virginia Polytechnic and State University, Blacksburg. 18p.

Chaney, W.R., Pope, P.E., and W.R. Byrnes. 1995. Tree survival and growth on land reclaimed in accord with Public Law 95-87. Journal of Environmental Quality. 24:630-634. http://dx.doi.org/10.2134/jeq1995.00472425002400040013x http://dx.doi.org/10.2134/jeq1995.244630x.

Foil, R.R. and C.W. Ralston. 1967. The establishment and growth of loblolly pine seedlings on compacted soils. Soil Science Society of America Proceedings. 31:565-568. http://dx.doi.org/10.2136/sssaj1967.03615995003100040037x.

Gomez, K.A. and A.A. Gomez. 1984. *Statistical Procedures for Agricultural Research*. John Wiley & Sons, New York. 680pp.

Gorman, J. and J. Skousen. 2003. Second year survival of commercial hardwoods on reclaimed minesoils in West Virginia. p. 279-291. *In* Proceedings of the American Society for Surface Mining and Reclamation, Billings, MT. June 3-6, 2003. American Society for Surface Mining and Reclamation, Lexington, KY.
`https://doi.org/10.21000/JASMR03010279`

Hatchell, G.E. 1970. Soil compaction and loosening treatments affect loblolly pine growth in pots. USDA Forest Service. Research Paper SE-72.

Howard, J.L., D.F. Amos, and W.L. Daniels. 1988. Phosphorus and potassium relationships in southwestern Virginia coal-mine spoils. Journal of Environmental Quality. 17:695-700. http://dx.doi.org/10.2134/jeq1988.174695x http://dx.doi.org/10.2134/jeq1988.00472425001700040029x.

Kost, D.A., J.P. Vimmerstedt, and J.H. Brown. 1998. Site factor effects on establishment of planted and volunteer trees and shrubs on graded cast overburden and replaced topsoil in southeastern Ohio. International Journal of Surface Mining and Reclamation. 12(2):79-86. http://dx.doi.org/10.1080/09208118908944027.

Kozlowski, T.T. 1999. Soil compaction and growth of woody plants. Scandanavian Journal of Forest Research. 14:596-619. http://dx.doi.org/10.1080/02827589908540825.

Larson, M.M., D.A. Kost, and J.P. Vimmerstedt. 1995. Establishment of trees on minesoils during drought and wet years. International Journal of Surface Mining and Reclamation. 9(3):99-103. http://dx.doi.org/10.1080/09208119508964728.

Li, R.S. and W.L. Daniels. 1994. Nitrogen accumulation and form over time in young mine soils. Journal of Environmental Quality. 23:166-172. http://dx.doi.org/10.2134/jeq1994.00472425002300010026x http://dx.doi.org/10.2134/jeq1994.231166x.

McGill, D.W., V.L. Ford, and J.F. McNeel. 2004, Early development of a species test established on surface mines thirty years post-reclamation. Proceedings America Society of Mining and Reclamation, 2004 pp 1227-1238 http://dx.doi.org/10.21000/JASMR0401227

Omi, S.K. 1985. Soil compaction: Effects on seedling growth. USDA Forest Service GTR RM-125.

Philo, G.R., C.A. Kolar, and W.C. Ashby. 1982. Effects of ripping on mine soil compaction and black walnut establishment. Symposium on Surface Mining Hydrology, Sedimentation and Reclamation. Lexington, KY.

Preve, R.E., J.A. Burger, and R.E. Kreh. 1984. Influence of mine spoil type, fertilizer, and mycorrhizae on pines seeded in greenhouse trays. Journal of Environmental Quality. 13:387-391. http://dx.doi.org/10.2134/jeq1984.133387x http://dx.doi.org/10.2134/jeq1984.00472425001300030013x.

Ramsey, C.L., S. Jose, B.J. Brecke, and S. Merritt. 2001. Growth response of longleaf pine (Pinus palustris Mill.) seedlings to fertilization and herbaceous weed control in an old field in southern USA. Forest Ecology and Management. 172:281-289. http://dx.doi.org/10.1016/S0378-1127(01)00795-2.

SAS Institute. 2001. SAS System for Windows V8. SAS Institute Inc., Cary, NC.

Shukla, M.K., R. Lal, and M. Ebinger. 2004. Soil quality indicators for reclaimed minesoils in southeastern Ohio. Soil Science. 169:133-142. http://dx.doi.org/10.1097/01.ss.0000117785.98510.0f.

Stanturf, J.A., C. van Oosten, D.A. Netzer, M.D. Coleman, and C.J. Portwood. 2001. Ecology and silviculture of poplar plantations. pp. 153-206. *In* Dickmann, D.I. et al. (eds.) Poplar Culture in North America. NRC Research Press, Ottawa.

Torbert, J.L. and J.A. Burger. 1996. Influence of grading intensity on herbaceous ground cover, erosion, and tree establishment in the southern Appalachians. *In* Proceedings of the American Society for Mining and Reclamation, Knoxville, Tennessee.
`https://doi.org/10.21000/JASMR96010637`

Torbert, J.L., J.A. Burger, J.E. Johnson, and J.A. Andrews. 1994. Final Report: *Indices for indirect estimates of productivity of tree crops*. OSM Cooperative Agreement GR996511. Virginia Polytechnic Institute and State University. 22p.

Torbert, J.L., J.A. Burger, J.N. Lien, and S.H. Schoenholtz. 1985. Results of a Tree -Species Trial on a Recontoured Surface Mine in Southwestern Virginia. *Southern Journal of Applied Forestry*. 9(3):150-153.

Torbert, J.L., J.A. Burger, S.H. Schoenholtz, and R.E. Kreh. 2000. Growth of Three Pine Species after Eleven Years on Reclaimed Minesoils in Virginia. *Northern Journal of Applied Forestry*. 17(3):95-99.

Torbert, J.L., J.A. Burger, and W.L. Daniels. 1990. Pine growth variation associated with overburden rock type on a reclaimed surface mine in Virginia. Journal of Environmental Quality. 19:88-92.

http://dx.doi.org/10.2134/jeq1990.19188x
http://dx.doi.org/10.2134/jeq1990.00472425001900010011x.

Torbert, J.L., J.A. Burger, and T. Probert. 1991. A reforestation case study on a reclaimed Appalachian mine soil in West Virginia. *In* Oaks, W. and J. Bowden (eds.) Technologies for Success. Proceedings of the American Society for Surface Mining and Reclamation Vol. 2. American Society for Surface Mining and Reclamation, Lexington, KY.
https://doi.org/10.21000/JASMR91020663

Van den Driessche, R. 1999. First-year growth response of four Populus trichocarpa x Populus deltoides clones to fertilizer placement and level. Canadian Journal of Forest Research. 29:554-562.
http://dx.doi.org/10.1139/x99-022
http://dx.doi.org/10.1139/cjfr-29-5-554.

Van den Driessche, R., W. Rude, and L. Martens. 2003. Effect of fertilization and irrigation on the growth of aspen (Populus tremuloides Michx.) seedlings over three seasons. Forest Ecology and Management. 186:381-389. http://dx.doi.org/10.1016/S0378-1127(03)00306-2.

Wendel, G.W. and H.C. Smith. 1990. Eastern White Pine. *In* Burns, R. M., and B. H. Honkala (tech. coords.) Silvics of North America: 1. Conifers. Agriculture Handbook 654. U.S. Department of Agriculture, Forest Service, Washington, DC. vol.2, 877 p.

Zisa, R.P., H.G. Halverson, and B.B. Stout. 1980. Establishment and early growth of conifers on compact soils in urban areas. USDA Forest Service. Research Paper NE-451.