FIRST-YEAR SURVIVAL AND GROWTH OF THREE SPECIES ASSEMBLAGES PLANTED ON RECLAIMED MINE LAND AS AFFECTED BY THREE LEVELS OF SILVICULTURAL INTENSITY

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Abstract—Surface mined land in the Appalachian coal-producing region have been found to exhibit growing conditions that are unfavorable for the establishment of productive forests including dense ground covers, compacted soil materials, and unfavorable soil chemical properties. To address these concerns, a 3 x 3 x 3 factor random complete block experiment was used to investigate the survival and height growth differences associated with three species assemblages across three levels of silvicultural intensity at three separate study sites. Hardwood survival was superior to both of the other species groups (69 percent versus 42 and 50 percent for white pine and hybrid poplar, respectively). Hybrid poplar grew far more in height (126.6 cm) over 1 year than either of the other species. Additionally, sites with sandstone-derived soils were found to have superior survival and growth compared to soils derived from shale or siltstone overburden. Hybrid poplar appears to have the greatest potential to revert reclaimed mine land to forest after it has already been reclaimed to grass cover.

INTRODUCTION

The Appalachian coal-producing region of the Eastern United States is predominantly forested prior to mining. The process of surface mining removes these forests and the native soils that support them. Current reclamation practices create adverse conditions for reclamation with trees, and consequently reforestation of surface mined lands has decreased since the passage of Surface Mining Control and Reclamation Act (SMCRA) of 1977 (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. Several studies have shown that these dense ground covers are detrimental to good survival and growth of tree species. For example, on a surface mine in Indiana, Andersen and others (1989) found that black walnut (*Juglans nigra* L.) and northern red oak (*Quercus rubra* L.) survival after 7 growing seasons increased from 4 and 1 percent, respectively, when planted into an existing dense ground cover to 66 and 48 percent, respectively, when planted after ground cover was controlled. Ashby (1997) found that the height of 16 different tree species combined were significantly taller with chemical weed control after 5 years.

Soil compaction on post-SMCRA reclaimed mined lands is also widespread. 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. Tillage treatments have been shown to ameliorate the detrimental effects of compaction. Ashby (1997) found that the mean height of 16 different tree species was significantly greater 5 years after ripping the mine soil to a depth of 1.2 m. Black walnut seedlings growing on a surface mine in southern Illinois were found to have taproot lengths which were 92 and 75 percent greater in their first and second years of growth, respectively, in ripped versus unripped plots (Philo and others 1982). This same study found overall rooting depth to be 81 and 58 percent greater in their first and second years in the ripped versus the unripped plots. Radial root growth was found to be 89 percent 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 the amount of oxidized sandstone in the growth medium was found (Torbert and others 1990). The rock types evaluated in this study consisted of pure sandstone, pure siltstone, and mixtures containing various proportions of each type. It is noteworthy that as pH decreased, stem volume increased to the extent that the pure sandstone plots (lowest pH) had five times more stem volume than in the pure siltstone plots (highest pH). Mine soils commonly have insufficient levels of N and P. Two separate studies of southwest Virginia mine soils have shown such deficiencies. In one, mine soils were found to have less total N than native soils and, of the total N, most was unavailable to plants (Li and Daniels 1994). In the other, spoils were found to have P-fixing capacities to the extent that P supply would still limit plant growth even after fertilization (Howard and others 1988).

Good survival and growth of trees is largely dependent on selecting the appropriate trees for a specific site based on site conditions and silvical characteristics. For this reason, survival and growth have been found to be extremely variable both between species and within the same species across different sites. For example, a study in southwest Virginia found white pine (*Pinus strobus* L.) survival after 11 years of growth to be 58 percent (Torbert and others 2000), whereas in a study in southeastern Ohio, no white pine survived after 3 years (Larson and others 1995). Several commercial hardwood species were found to have excellent survival after 2 years on a mountain-top-removal mine in West Virginia treated with weed control and tillage (Gorman and Skousen 2003). Conversely, Torbert and Burger (1996) found only 3 percent

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survival for yellow poplar (*Liriodendron tulipifera* L.) in areas where no ripping or weed control had been employed.

The objective of this investigation was to evaluate the first-year survival and growth of three species assemblages under three levels of silvicultural intensity intended to alleviate the three common limiting conditions for tree establishment and growth on reclaimed mine land. Assemblages were installed at three sites, each with different site characteristics.

METHODS

The study used a 3 x 3 x 3 random complete block design to evaluate: (1) the effects of site conditions at each of three sites, (2) the three levels of silvicultural intensity, and (3) the effects of the three species assemblages on first-year survival and height growth. Study sites were located in Lawrence County, OH, Nicholas County, WV, and Wise County, VA. Species assemblages included: (1) hybrid poplar [*Populus trichocarpa* L. (Torr. and Gray ex. Hook) x *Populus deltoids* (Bartr.ex Marsh.) hybrid 52-225]; (2) white pine; and (3) native hardwood mix intended to mimic the premining forest composition at each site based on species composition of adjacent unmined forests. The treatments included: (1) weed control only (WC); (2) weed control plus tillage (WC+T); and (3) weed control plus tillage plus fertilization (WC+T+F). All trees were planted at 2.4 m x 3.0 m spacing for a final planting density of 1,345 trees ha-1. Plots were blocked within each site based on soil properties. Nine 0.25-ha 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 < 15 percent.

The weed control treatment consisted of 9.351 ha^{-1} of glyphosate broadcast over each site in August, 2003. After planting in April, 2004, pendimethalin was broadcast at a rate of 4.921 ha^{-1} for pre-emergence control of weeds. Spot applications of glyphosate were made to each tree in June, 2004, to provide additional competition control. Seedlings were shielded from drift during this application.

The tillage treatment employed was ripping. Depth of ripping was set between 61 and 91 cm. The equipment used to install the tillage treatment varied based on local equipment variability but was consistent within blocks and included: single shank only, single shank with coulters creating beds, and multiple shanks resulting in tillage of the entire site. Tillage was carried out prior to planting in April, 2004.

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

The site in Lawrence County, OH was characterized by fine-textured spoils derived primarily from siltstone. This site had an oxidized topsoil replaced across the site that ranged from 5 to 51 cm deep. The spoil material under the topsoil was near alkaline (pH=6.64 versus 5.38 in the topsoil) and had much higher electrical conductivity than the topsoil (0.47 dS m^{-1} versus 0.10 dS m^{-1}). This site had been supporting a dense grass cover for at least 10 years. The Nicholas County, WV site was characterized by a coarse-textured soil with a high coarse fragment percentage (50 to 60 percent). These soils were derived from shale overburden. The site had been used for grazing prior to study establishment and had been supporting grass cover for at least 10 years. The Wise County, VA site also had coarse-textured spoils and high coarse fragment content; however, this site had oxidized sandstone topsoil replaced to depths ranging from 0 to 47 cm across the site. This site had been supporting grasses for < 10 years.

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

Analysis of covariance was used to analyze white pine and hardwood data using initial height as a covariate. Hybrid poplar were planted from woody cuttings and had no initial height; consequently analysis of variance was used to analyze data for this species. Hardwood species used in the analysis included red oak, sugar maple (*Acer saccharum* L.), and yellow poplar, as these species were common to all three sites. Survival data was transformed using the arcsine transformation and height growth data using the natural log transformation prior to analysis of variance/covariance to satisfy the assumptions associated with those procedures (Gomez and Gomez 1984). Analysis was done by species due to the different analysis procedures used. Additionally, analysis was done by site and by treatment if the site x treatment interaction was significant after analysis by species. 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 2001) was used for all statistical analyses.

RESULTS

Survival

In general, hardwoods had the best survival across sites and treatments (69 percent) followed by hybrid poplar at 50 percent with white pine having only 42 percent survival across sites and treatments. Site effects on survival showed that the site in Virginia (VA) had the highest mean survival for all species and that the Ohio site (OH) had the lowest (fig.1). For hybrid poplar, survival at the VA site (72 percent) was significantly higher than that at either of the other sites (37 and 41 percent for OH and WV, respectively). For hardwood, survival in VA was significantly higher than that in OH (82 versus 48 percent respectively). The site x treatment interaction was significant for white pine ($P=0.0428$).

Treatment effects on survival revealed that WC+T gave the highest mean survival across sites for each species while WC+T+F resulted in the lowest mean survival. This difference was significant for both hardwood and hybrid poplar (81 and 59 percent for hardwood versus 54 and 37 percent for hybrid poplar for these treatments, respectively; fig. 2). Examination of the site x treatment interaction for white pine revealed that in OH, survival decreased as the level of silvicultural intensity increased, whereas in VA and WV survival was increased as a result of WC+T (fig.3).

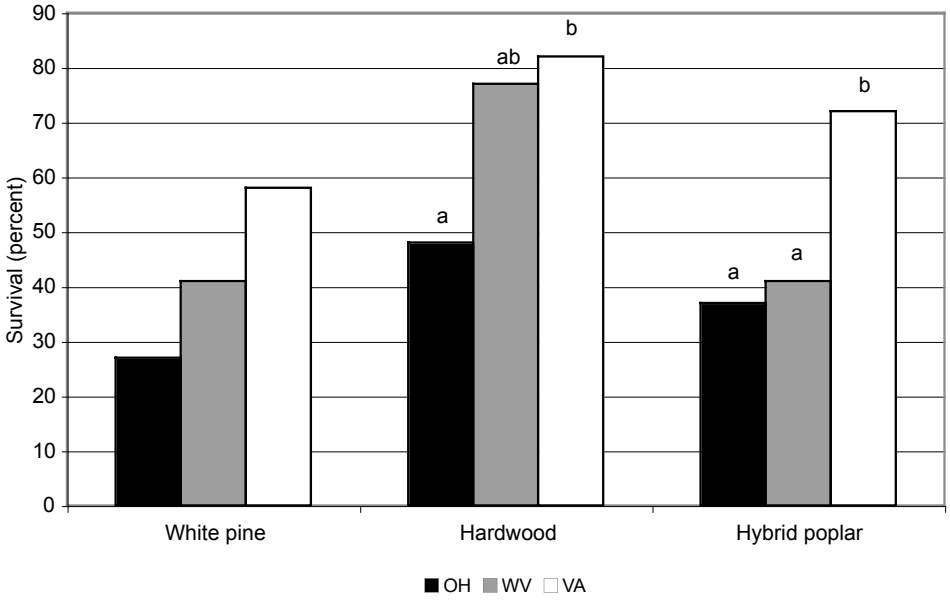

Figure 1—Site effects by species on survival of three species assemblages planted on reclaimed surface mines in Lawrence County, OH, Nicholas County, WV, and Wise County, VA under three levels of silivicultural intensity. For each species, bars with the same letter are no different at P<0.05.

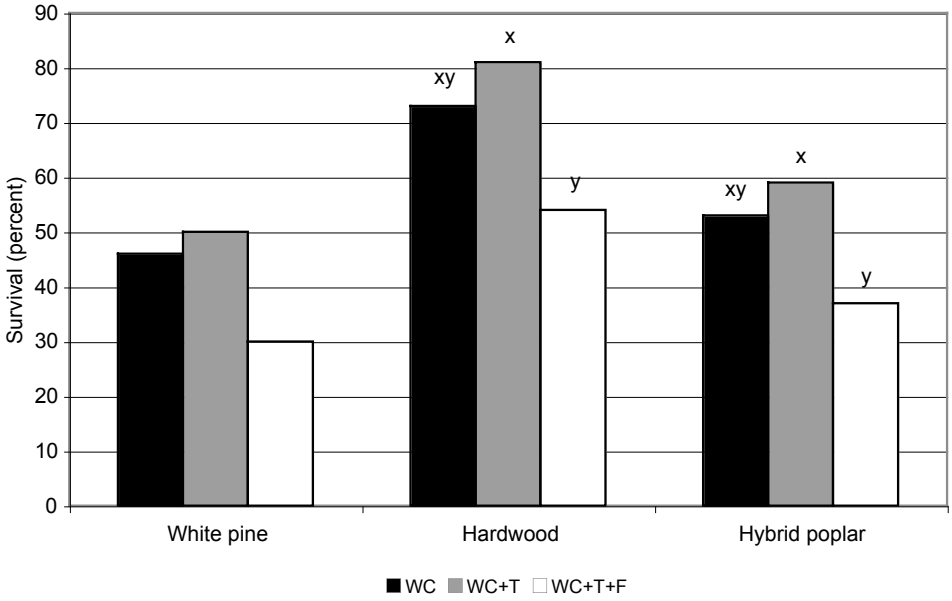

Figure 2—Treatment effects by species on survival of three species assemblages planted on reclaimed surface mines in Lawrence County, OH, Nicholas County, WV, and Wise County, VA under three levels of silivicultural intensity. For each species, bars with the same letter are no different at P<0.05.

Height Growth

Hybrid poplar grew far more in height than hardwoods or white pine. Average height growth for hybrid poplar across sites and treatments was 56.7 cm compared to 6.2 cm for white pine and –2.0 cm for hardwood. Hardwood species often died back to heights shorter than their initial height after planting, resulting in negative height growth. Height growth of white pine was no different between sites and ranged from 5.8 to 6.7 cm (fig.4). For hardwood, height growth ranged from –6.3 cm in OH to 1.3 cm in VA; the difference between these two sites was significant. There was significant site x treatment interaction for hybrid poplar (P=0.0308).

There were no treatment effects for hardwood or white pine with height growth of white pine ranging from 5.6 cm in WC to 6.7 cm in WC+T to 6.2 cm in WC+T+F (fig.5). Hardwood height growth ranged from –2.1 cm in WC to –4.4 cm in WC+T to 0.4 cm in WC+T+F. The site x treatment interaction for hybrid poplar revealed a synergistic effect of WC+T+F on height growth of this species in VA, where height growth averaged 126.6 cm (fig.6). This was nearly double the height growth of the second-highest response, which was also in VA for the WC+T treatment (65.4 cm). In WV, WC+T and WC+T+F both resulted in significantly more height growth than WC (60.2 cm

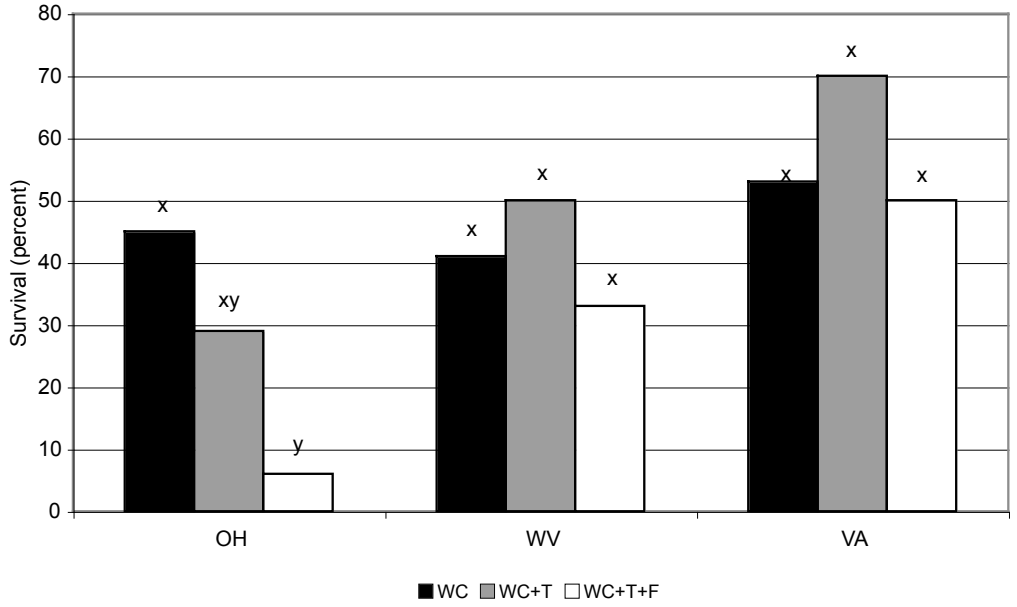

Figure 3—White pine survival percentage site by treatment interaction for trees planted on reclaimed surface mines in Lawrence County, OH, Nicholas County, WV, and Wise County, VA under three levels of silivicultural intensity. For each site, bars with the same letter are no different with respect to treatment at P<0.05.

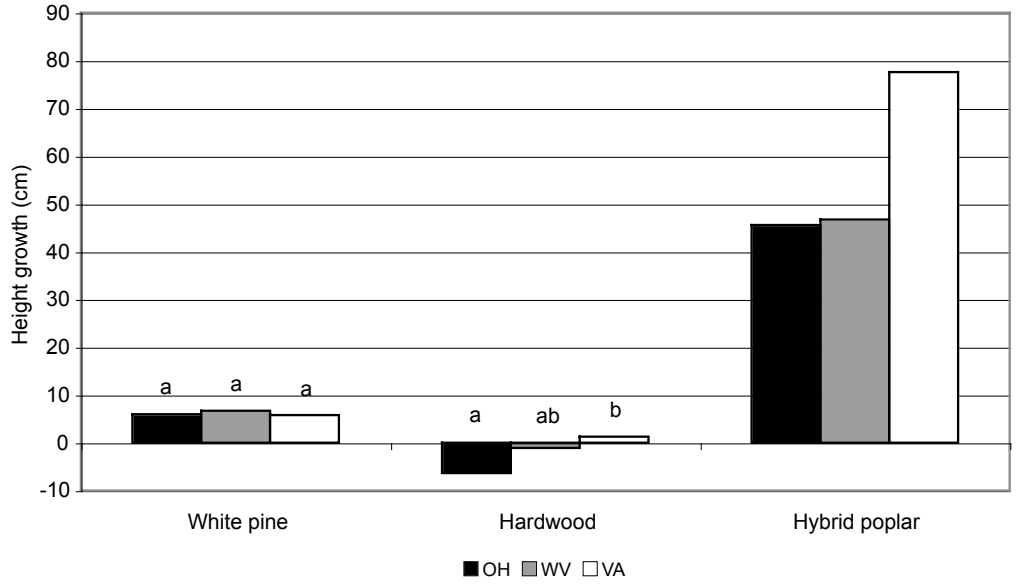

Figure 4—Site effects by species for height growth of three species assemblages planted on reclaimed surface mines in Lawrence County, OH, Nicholas County, WV, and Wise County, VA under three levels of silivicultural intensity. For each species, bars with the same letter are no different at P<0.05.

and 57.6 cm versus 22.4 cm respectively). There was no treatment response for hybrid poplar in OH where heights ranged from 35.8 cm in WC to 50.8 cm in WC+T+F.

DISCUSSION

The results of this study indicate that there is likely no universal prescription for good establishment and first year growth of the species used in this study, since 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 was conducted on three surface mines in West Virginia using species similar to those in this study. McGill and others (2004) found that in plots receiving similar treatments to the WC+T+F treatment, the same hybrid poplar clone averaged 1.0 m in total height after 1 year, and average first-year survival for the hybrid was 79 percent across all 3 sites. In this study, we found overall survival was lowest in OH; white pine had the lowest survival of the three species assemblages at this site. Larson and others (1995) found that white pine survived and grew poorly on sites in this geographic area with the near alkaline and fine-texture

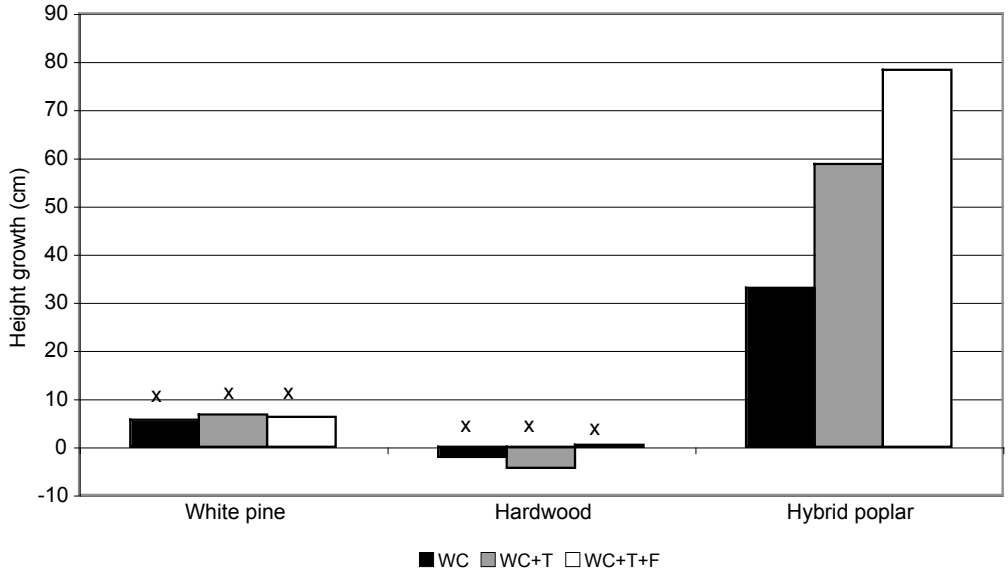

Figure 5—Treatment effects by species for height growth of three species assemblages planted on reclaimed surface mines in Lawrence County, OH, Nicholas County, WV, and Wise County, VA under three levels of silivicultural intensity. For each species, bars with the same letter are no different at P<0.05.

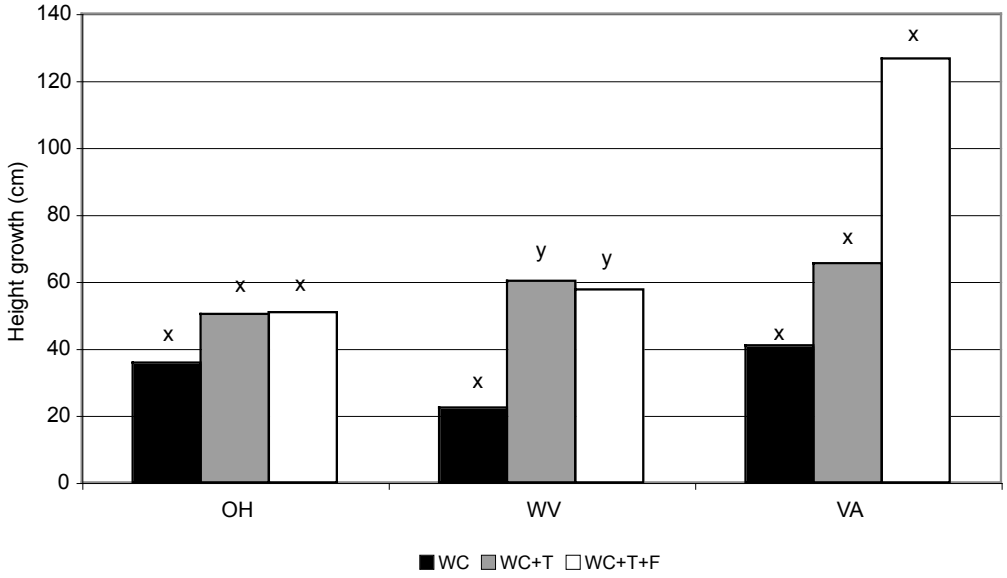

Figure 6—Hybrid poplar height growth site by treatment interaction for trees planted on reclaimed surface mines in Lawrence County, OH, Nicholas County, WV, and Wise County, VA under three levels of silvicultural intensity. For each site, bars with the same letter are no different with respect to treatment at P<0.05.

spoil materials common to the area. One explanation for poor survival and growth of white pine in OH would be that white pine performs best on well-drained soils within its native range (Wendel and Smith 1990), and the soils in OH had fine textures, no soil structure, and many areas with hydrophytic vegetation, indicating anaerobic conditions and poor drainage.

For all species, WC+T+F decreased survival below that of the WC treatment and significantly below that in WC+T. Two hypotheses exist for decreased survival in the WC+T+F treatment: (1) Fertilization stimulated the competing vegetation (Ramsey and others 2001). Despite uniform herbicide applications to all sites, competing vegetation was greater in OH than at the other sites and notably greater in the tree rows where fertilizer was banded. (2) A salt effect was created by the fertilizer, leading to moisture stress in the trees. Diammonium phosphate and muriate of potash fertilizers are considered to pose moderate and high salt hazards, respectively (Brady and Weil 2002). In OH, a combination of these two factors would be likely; tillage at this site would have brought the siltstone spoil, which has been shown to negatively affect pine growth (Torbert and others 1990), close to the surface. The salt levels of this spoil (0.47 dS m^{-1}) are close to levels suggested by Torbert and others (1994) (0.05 dS m^{-1}) as negatively affecting tree growth. This salt effect would be compounded by adding fertilizer to the spoil; the soil has

poor drainage, and therefore excess salts could not be readily leached out of the rooting zone.

Tillage has been shown to improve tree survival and growth through reduction of bulk density on surface mines (Ashby 1996, Torbert and Burger 1996). Tillage produced mixed results in terms of survival and growth response in this study. There was no response to tillage in OH for any species in terms of height growth nor was there a survival difference associated WC+T when compared to WC. This could be due to an ineffective tillage treatment resulting from tilling these fine-textured soils when they were saturated. Shukla and others (2004) found that on mine soils in southeastern OH similar to the ones in our study, bulk density was an important variable in determining site quality and failure to improve bulk density would logically be associated with failure to improve survival or height growth. In WV, WC+T failed to significantly improve survival, though mean survival was higher in WC+T than in WC for all species. Alternatively, height growth of hybrid poplar at this site nearly tripled compared to the WC treatment, indicating that soil compaction was a major limitation for good growth at this site. An inverse relationship between soil density and several plant growth measures has been found by researchers. For example, Foil and Ralston (1967) found such a relationship between bulk density and root length and weight for loblolly pine (*Pinus taeda* L.), and Hatchell (1970) found a similar relationship between bulk density with shoot and root weights for loblolly pine. Zisa and others (1980) found an inverse relationship between bulk density and depth of root penetration for three conifer species. Alhough soil physical properties in VA were similar to those in WV, there was no significant response to WC+T at this site compared to the WC treatment. This could be due to the increased water-holding capacity of the loam-textured soil and the lower coarse fragment percentage of the sandstone spoil at the VA site compared to the sandy loam texture and higher coarse fragment content at the WV site. Torbert and others (1990) found that whole soil water-holding capacity was greater in pure sandstone spoil with lower coarse fragment contents than in finer-textured siltstone spoils.

Comparing the effects of WC+T+F between WV and VA, it is important to consider that the site in WV was likely fertilized to maintain the lush grass cover for grazing cattle, as indicated by much higher N and P levels in the soils from this site. For this reason, trees at this site likely had all the nutrients they needed prior to the fertilization treatment. The synergistic response to WC+T+F for hybrid poplar on the sandstone spoils in VA is logical given that these soils are inherently low in N and P (Howard and others 1988, Li and Daniels 1994) and that hybrid poplar have been shown to respond favorably to fertilization (van den Driessche 1999).

CONCLUSIONS

Hardwood species had the highest survival across sites and treatments, with white pine having the lowest survival. Both of these species were unresponsive to treatment in terms of first-year height growth. This lack of height growth could translate into continued weed control to ensure these species aren't out-competed by the weeds at these sites.

For hardwood and white pine, WC+T would likely be the optimum treatment. This treatment gave the highest mean survival for all species, and any increased height growth as a result of WC+T+F may not offset the decreased survival that resulted from this treatment.

Sites with oxidized sandstone soil materials appear to be the most favorable for tree establishment and growth given the species and treatments used in this study. Shale-derived soils appear to be less suitable and, on fine-textured siltstone-derived spoils, other species and/or treatments may be needed to ensure an adequately stocked productive stand develops.

Hybrid poplar is likely the best alternative of the tree species used. This species attained heights in excess of 50 cm at all sites within 1 year and as such decreased the chances of these trees succumbing to the competing vegetation. The best combination of species, treatments, and site characteristics occurred in VA where hybrid poplar, in combination with the WC+T+F treatment and oxidized sandstone spoils, attained an average height of 126.6 cm in 1 year.

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