Effects of Silvicultural Treatments and Soil Properties on the Establishment and Productivity of Trees Growing on Mine Soils in the Appalachian Coalfields

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EFFECTS OF SILVICULTURAL TREATMENTS AND SOIL PROPERTIES ON THE ESTABLISHMENT AND PRODUCTIVITY OF TREES GROWING ON MINE SOILS IN THE APPALACHIAN COALFIELDS

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ABSTRACT

Coal has been and will continue to be an important energy source in the U.S. for the foreseeable future. Surface mining for coal is one of the methods employed to extract this resource from below the ground. The process of surface mining removes native topsoils and any native vegetation that was supported by these native soils. In the Appalachian coal-producing region of the United States, the pre-mining landscape is predominantly forested. Prior to the Surface Mining and Reclamation Act of 1977 (SMCRA), surface mined lands were commonly reclaimed to forests. Subsequent to the passage of SMCRA, reforestation of surface mined lands has decreased. As a result, thousands of hectares of land that were forested prior to mining are being reclaimed using grasses and legumes. This is done in spite of the fact that the SMCRA requires that land be reclaimed to an "equal or higher land use." The decline of reforestation stems from two main issues, namely: (1) reclaiming land to pasture is an easy and low-risk way for mining companies to obtain bond release; and (2) SMCRA reclamation requirements have led to unfavorable conditions for tree establishment and growth. Recent interest has been shown in reverting these surface mined lands that have been reclaimed to pasture back to forests for reasons related to the environmental, economic, and carbon sequestration benefits that forests are believed to have when compared to pasture land. It is believed that forests can be established on existing reclaimed pasture land through the use of silvicultural treatments, that mature stands of trees growing on surface mines will

respond to treatment similarly to stands growing on native soils, and that mature stands growing on relcaimed surface mines have different soil properties controlling their growth than those that have been found for younger stands. The purpose of this investigation was to understand the biological feasibility of restoring forests on post-SMCRA surface mined lands in the Appalachian coalfields reclaimed to pasture and to understand the productive potential and factors governing the productive potential of pre-SMCRA surface mines supporting mature forests in an attempt to show the benefits of reclaiming these lands with forests.

A 3x3x3 factor random complete block design was used to assess first-year survival and growth of three species assemblages under three levels of silvicultural treatment intensity at each of three study sites having different site characteristics. The native hardwood species assemblage was found to have the best survival across all three sites, with 80 and 85% survival for sites with spoils derived from shale and oxidized sandstone, respectively. White pine generally had the lowest survival of all species and ranged from 27% across treatments on siltstone spoils to 58% across treatments on oxidized sandstone spoils. Hardwood and white pine grew little over the first year, ranging from -3.7 to 8.9cm in height compared to hybrid poplar, whose height growth ranged from 22.4cm to 126.6cm. Response to silvicultural treatment was variable by site and species, but weed control in combination with tillage generally resulted in the highest survival. Greatest height growth (126.6cm) occurred on the oxidized sandstone spoil, where hybrid poplar was treated with weed control plus tillage in combination with fertilization. Hybrid poplar was found to have the greatest growth after one year compared with the hardwood and white pine and also had the greatest height growth at each level of silvicultural intensity for all sites. This superior growth should give hybrid poplar an advantage over the others used to revert these grass lands back to forests, as the amount of height growth observed (>50cm over one year in the weed control plus tillage treatment at all sites) may be enough to ensure that these trees will not succumb to aggressive competing vegetation without further weed control. The results of this study show that based on first-year data, reforestation of these lands does appear to be biologically feasible, given the species and treaments used.

In an attempt to quantify the productivity of a 26-year-old white pine stand established pre-SMCRA, a random complete block experiment was used to compare the response to a thinning that occurred in this stand at age 17. Site index of the stand was found to be 32.3m at base age 50, indicating that this is a very productive stand. Neither stand volume nor stand value was statistically different at age 26 between treatments with volumes and values ranging from 290m^3ha^{-1} and \$5639 ha^{-1} to 313 m^3ha^{-1} and \$5478 ha^{-1} for the thinned and unthinned treatments, respectively. The difference in mean breast-height diameter, however, was significant at age 26, and this was confirmed by a significant difference in a repeated measures analysis of annual diameter data for these treatments ($P < 0.0001$). Projection to age 30 revealed that both stand volume and value would be significantly higher in the thinned treatment by margins of 8.7 m^3 ha^{-1} and \$2457 ha^{-1}. Regression analysis of soil data within the observed rooting depth of the trees from this stand indicated that nitrogen mineralization index, bulk density, sand percentage of the fine soil fraction, and percentage of oxidized sandstone in the soil profile were the most important variables in determining the stand's productive capacity ($R^2 = 0.7174$). It was also found that of the five different spoil types encountered in the stand, the oxidized sandstone spoil had the most favorable physical and chemical properties for tree growth. Common root-restricting layers were found to have high soil density or increased levels of soluble salts.

It has been shown that reclaimed surface mines can grow productive forests if the appropriate spoil materials are returned to the surface in sufficient depth. It has also been shown that surface mined lands reclaimed to pasture can be successfully reforested using silvicultural treatments to ameliorate unfavorable conditions for tree establishment and growth, though these treaments may not be cost-effective, and the success of these treatments was variable based on the soil characteristics of each site.

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CHAPTER I. INTRODUCTION

Surface mining for coal has provided and will continue to provide an important source of energy to the United States. The United States Department of Interior's Office of Surface Mining reports that from 1978 to 2002, more than 23 billion tons of coal have been mined commercially in the United States (OSM, 2003). Of this amount, approximately 11.4 billion tons have come from the states that comprise the Appalachian coal-producing region. This is nearly 50% of the total produced in the United States during this period, indicating the importance and extent of coal mining in this region.

All surface mined lands disturbed 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 mandated that reclamation be carried out on all surface mined lands, and set forth criteria for coal operators to follow in carrying out reclamation practices. Many of these criteria have created adverse conditions for reclamation with trees, and consequently, reforestation of surface mined lands has decreased since the passage of SMCRA (Ashby, 1991).

The most common conditions created by SMCRA reclamation practices that adversely affect tree survival and growth are soil compaction, competition from herbaceous vegetation, and unfavorable chemical properties of the soil in which the trees are being established. Soil compaction on post-SMCRA reclaimed mined lands is 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, 1986). Excessive competing vegetation is a direct result of sowing aggressive ground covers 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 invasive grasses and legumes compete with tree seedlings for light, water and nutrients (Ashby, 1991). The chemical properties associated with any given mine soil can be controlled to an extent by selecting overburden materials that are known to have the desired chemical properties for tree establishment and growth. For example, high-pH siltstone spoil has been found to adversely affect pine survival and growth (Larson et al., 1995).

The previously mentioned decrease in reforestation of surface mined lands has taken place in spite of the fact that several viable commercial forests have been established on reclaimed surface mines (Rodrigue et al., 2002; Davidson, 1979; Ashby, 1996b). In an effort to promote reforestation of surface mined lands, reports of the commercial viability of currently mature stands of timber growing on reclaimed surface mines is important. Additionally, there are very few reports of how these stands respond to intermediate stand treatments such as thinning.

The productive potential of forests on reclaimed surface mines is intricately linked to the soil and site upon which the trees are growing. Several researchers have related mine soil properties to tree growth; however, most of these investigations have taken place on young stands that have been established on fresh spoil (Andrews et al., 1998;

Torbert et al., 1988). There have been few studies that have attempted to characterize soils that currently support productive forests and to predict the soil properties that would be important to good growth in these mature stands. It is believed that forests can be established on existing reclaimed pasture land through the use of silvicultural treatments, that mature stands of trees growing on surface mines will respond to treatment similar to stands growing on native soils, and that mature stands have different soil properties controlling their growth than have been found for younger stands growing on reclaimed surface mined land.

To address the previously mentioned problems and information gaps associated with reforesting surface mined land, a series of investigations were designed with the following objectives:

1. Evaluate the effects of three levels of silvicultural input on survival and first-year growth of three species assemblages at three different sites in the Appalachian coal producing region, each having distinct site characteristics.
2. Evaluate the effects of three levels of silvicultural input on the biomass, nutrition, and water relations of hybrid poplar growing on a site in Nicholas County, West Virginia.
3. Examine the volume and value growth response to thinning of a productive pre-SMCRA white pine stand in Wise County, Virginia.
4. Characterize soil properties of a mature and productive pre-SMCRA white pine stand in Wise County, Virginia, and determine which properties are most important to the stand's productive capacity.

CHAPTER II. LITERATURE REVIEW

Successful Reforestation of Surface Mined Land Pre-SMCRA

The Surface Mining Control and Reclamation Act of 1977 set forth criteria for mining companies to follow in carrying out reclamation. While these criteria have resulted in numerous benefits to the environment through such things as reduction of acid mine drainage and greater slope stability, the fact remains that most of the lands reclaimed after the law was enacted are not productive compared to those reclaimed prior to enactment of the law, which have been shown to support productive forests. For example, Ashby (1996b) found that black walnut (*Juglans nigra* L.) growing on a pre-SMCRA site in southern Illinois had heights greater than the highest site index value reported for Central States plantations. This same study also revealed that of the 12 species studied, average height was 21m and average diameter was 28cm after 47 years of growth. In a study of a reclaimed surface mine in Pennsylvania, hybrid poplar (*Populus* spp.) that were planted in 1962 were found to average 25.4cm in diameter and 19.8m in total height after 16 growing seasons. Volume growth for these trees was equal to approximately 17.9m^3 ha^{-1} yr^{-1} (Davidson, 1979). On an anthracite spoil in eastern Pennsylvania, Czapowskyj (1978) found that on one of three study blocks on the mine spoil, several hybrid poplar clones had attained an average height of 14.4m and dbh of 13.9cm. While the other two study blocks averaged only 6.1m in height and 5.1cm dbh, both measures were greater than those found for the same tree species on native glacial till soils (5.9m in height and 4.7cm dbh). In a study of old Pennsylvania surface mines (planted between 1919 and 1938), of the 19 stands evaluated, Davidson (1981) determined that most trees in these stands were of merchantable size, and furthermore, there were timber volumes present in most stands to support a commercial harvest.

More recently, in a study comparing the productivity of pre-SMCRA reforested areas to native forests throughout the Appalachian and Midwestern coalfields, Rodrigue et al. (2002) found that of the 14 mined sites inventoried, six were more productive than their associated non-mined control sites and seven were equally as productive as their non-mined controls.

Productivity Differences: Pre- vs. Post-SMCRA

Ashby (1998) conducted a study comparing 10-year survival and growth of tree species planted pre- and post-SMCRA under different soil compaction regimes in southern Illinois. For the pre-SMCRA sites, the compaction treatments were ungraded and leveled. For the post-SMCRA sites, the compaction treatments were: ungraded; graded to approximate original contour (AOC) standards; and graded to AOC standards with topsoil replaced. It was concluded that both pre-SMCRA sites displayed good survival and growth, while only the ungraded post-SMCRA site was able to support good tree survival and growth in terms of volume production per unit area per year.

Torbert and coworkers (2000) carried out a study that compared the productivity of three different pine species on a pre-SMCRA bench site and a post-SMCRA "approximate original contour" site. In this case, it was found that although the bench site had higher initial survival and growth rates, after 11 years both sites are growing at similar rates. The authors did note that neither site had bulk density levels that would greatly restrict tree growth.

According to Ashby (1991), this disparity in productivity between pre- and post-SMCRA sites is directly attributable to the dense ground cover required by the law for erosion control, as well as what he calls "the seemingly implacable provision of SMCRA…grading to approximate original contour" and its associated compaction problems.

Influence of Competing Vegetation on Successful Reclamation with Trees

One common problem associated with current reclamation procedures with the goal of establishing trees is the dense ground cover that is planted to prevent erosion on intensively graded sites. This problem has been well documented in the literature on post-SMCRA tree plantings (Andersen et al., 1989; Ashby, 1991; Ashby, 1997; Torbert et al., 2000). Chemical weed control is one treatment shown to be effective in controlling competition from grasses. It is a common practice on managed forest land, so it is reasonable to assume that it would be a good practice on surface mined land where grasses are often established before trees are planted. Another common treatment for controlling competing vegetation is to establish a "tree-compatible ground cover" at the time of tree planting (Burger and Zipper, 2002). Of course, this option is not available on surface mined lands that have already been reclaimed to dense grasses.

Referring again to Ashby (1991), he stated that one of the two "well documented causes of failure of trees under SMCRA" is the "detrimental effect of ground cover." He cited competition for moisture and nutrients, competition for light, and allelochemical interactions between grasses and tree seedlings as the major problems associated with competing ground cover. He also noted that ground cover is associated with increased populations of rodents and deer, which feed on tree seedlings and adversely affect tree survival and growth.

On a surface mine in Indiana, Andersen et al. (1989) found that black walnut and northern red oak (*Quercus rubra*) survival increased from 4% and 1% respectively with no ground cover control to 66% and 48% respectively with ground cover control. It was also found that height growth was significantly better on the mine site where weeds were controlled. These results were based on observations after seven growing seasons. It was also noted that on the mine site, adequate stocking of trees (1110 trees ha^{-1}) required to meet the specifications of SMCRA was only attained when the ground cover was controlled chemically. The 12-year results of this study again showed that height growth was enhanced by weed control and that survival was 2% and 0.2% for black walnut and red oak respectively when no weed control was employed, and 61% and 39% for the same species respectively when weed control was employed (Chaney et al., 1995).

Torbert et al. (2000) found that after five years, average tree height growth for three pine species was 66cm greater in plots where ground cover was controlled than in plots where it was not. The same study reported that after 11 years, the difference in average tree height increased to 158cm, which shows that ground cover control has effects lasting for more than a few years after the trees become established. Survival also increased for all species when ground cover was controlled.

A species trial on a surface mine in southwestern Virginia showed that using a systemic herbicide to control grasses in half of the study plots significantly increased the survival of cottonwood (*Populus deltoides* Bartr. ex Marsh.), sycamore (*Platanus occidentalis* L.), white ash (*Fraxinus americana* L.), loblolly pine (*Pinus taeda* L.), and

Virginia pine (*Pinus virginiana* P. Mill.), though none grew better as a result of the treatment (Torbert et al., 1985). These results demonstrate the inability of these relatively intolerant tree species to compete with a dense cover of grasses during their establishment period.

On a surface mine in West Virginia, a mowing treatment was applied to eliminate ground cover competition surrounding trees. This treatment was found to have mixed effects in terms of tree survival due to the dense vegetation created by mowing and its associated increase in moisture competition with the planted trees (Gorman and Skousen, 2003).

Larson et al. (1995) found that in terms of green ash (*Fraxinus pennsylvanica* Marsh.) survival, seeding a grass legume mixture the fall before planting gave a 40% survival rate, seeding only legumes gave a 94% survival rate, and seeding only grasses resulted in a 47% survival rate. These findings again make the case for the need to eliminate grass competition completely, or to sow a more "tree-compatible ground cover" in order to successfully establish trees on surface mines.

Controlling competing vegetation has been shown to be a necessary treatment in order to successfully establish a productive stand of trees on reclaimed surface mines. While sowing a tree-compatible ground cover at the time of tree planting is likely the most efficient means of keeping competition in check, the fact remains that there are many thousands of hectares of land already planted to dense grasses. When the latter condition exists and forests are the desired land use, chemical weed control seems to be the best option and has proven to be very effective.

Mine Soil Physical Properties and their Limitations to Tree Productivity

The effects of soil compaction on the survival and growth of trees have been well documented. In reviewing literature on soil compaction and plant productivity, a complex interaction among many specific soil properties confuses the issue of exactly how soil compaction affects plant growth. In a review of the effects of soil compaction on root growth and tree vigor, Ruark et al. (1982) concluded that the soil surrounding a tree should be viewed as a matrix system and that this matrix consists of soil compaction, aeration, moisture, and temperature. Trouse (1971a) added a fifth factor to the previously mentioned matrix, which would be soil nutrient availability. The importance of understanding each of the five indirect effects of soil compaction lies in the fact that they interact greatly in their effect on plant productivity, and it becomes very difficult to separate the effects attributable to any one of the five factors.

Soil compaction in mine soils typically results from 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. Additionally, when sites are to be planted to grasses, mine soils are often “tracked in,” which further compacts the soil in an effort to create a seedbed conducive to the establishment of grasses.

Various techniques have been experimented with in order to ameliorate compaction problems associated with current reclamation practices. The two most common treatments used have been loosely dumping spoil materials at the final reclamation surface and tillage of some sort. One study found that for three high-value hardwood species grown on a surface mine in eastern Kentucky, average survival, height growth, and seedling vigor were higher on plots where soil was loosely dumped as opposed to plots that were compacted to simulate current reclamation practices (Thomas, 1999). Loose dumping and similar treatments are good solutions for active reclamation, but provide no answer for mine soils that have already been compacted during reclamation.

The most common form of tillage is using a rock ripper to break up compacted layers. While ripping has shown varying degrees of success in terms of increasing tree survival and growth, in almost all cases it has increased tree survival and growth when compared to similar plots which have not been ripped. The net effect of ripping mine soil is a lower bulk density, which translates into lower soil strength (Cleveland and Kjelgren, 1994) and a better rooting environment for trees.

In addition, the rooting environment after ripping is usually much more aerated and well drained. Poor aeration in compacted soils arises when compacted layers perch water, creating a poorly aerated environment, which can potentially limit root development. Poor aeration can restrict growth through reduced oxygen content, increased carbon dioxide concentration (or other potentially toxic anaerobic gases), or both (Trouse, 1971b). Compacted layers are common on surface mines (Daniels and Zipper, 1997; Bussler et al., 1984) despite the fact that many of these mine soils are over 50% coarse fragments. Evidence of the severe compaction that can occur on reclaimed landscapes can be found in Hearing and coworkers (2004) and Atkinson and coworkers (1996), who found hydric soil indicators and hydrophytic vegetation on reclaimed surface mines in southwestern Virginia.

Soil strength is a measure of the mechanical resistance of soil to an applied force (Omi, 1986). Soil strength affects plant growth in that roots are only able to penetrate pores that are greater in size than the root itself without exerting a force on the soil to expand the size of the soil pore (Ruark et al., 1982). This means that if the strength of the soil is too great, the root essentially hits a "dead end." The effect of increased soil strength on roots is a reduced rate of elongation as well as a reduced number of roots that are able to penetrate the compacted layer (Taylor, 1971). Cleveland and Kjelgren (1994) found that deep tilling a mine soil to 0.7m with a vibrating shank doubled the cross-sectional area of low impedance soil from 0.29 to 0.58 m^2. This study also found that within the depth that was ripped, bulk density was lower than that of unripped plots.

Rooting depth is also increased through ripping when traffic pans near the surface are shattered, allowing roots to penetrate to depths below the former traffic pans. Rooting depth is directly related to nutrient supply; thus, any of the indirect effects of soil compaction that restrict root growth decrease the supply of available nutrients by decreasing the exploitable rooting volume of the plant (Russell, 1977; Parish, 1971). This can have more pronounced effects in infertile soils, where plants need a larger exploitable rooting volume to compensate for the nutrient-deficient nature of the soil.

Ashby (1997) found that the mean height of 16 different tree species combined, as well as all species individually, in all five years of the study, showed significant increases in height growth at the 0.01 probability level (with the exception of *Liquidambar styraciflua,* which was significant at the 0.05 level) as a result of ripping the 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, 1996a).

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. For the second year only, radial root growth was found to be 89% greater in the ripped plots. In terms of bulk density of the soil, the upper 15cm of the soil went from 1.5g cm^{-3} prior to treatment to 1.1g cm^{-3} after ripping, while the 15- to 30cm depth went from 1.6 to 0.9g cm^{-3}. Both of these were significant at the 0.01 level using a one-tailed t-test. By improving the rooting conditions for black walnut, aboveground tree growth was also improved. In the second year of growth, stem diameter was increased from 10.6mm in the unripped plots to 15.5mm in the ripped plots (significant at the 0.01 level of a one-tailed t-test).

Gorman and Skousen (2003) found that the survival of five commercially valuable hardwood species increased as a result of ripping to a 1m depth. The authors also noted that the effects of ripping on the survival of trees on south aspects were much more pronounced than those on north aspects, and they cited improved water relations on the droughtier south aspects as the probable cause of this increased survival.

One study in which soil ripping was not found to create a statistically significant increase in tree survival and growth was carried out by Kost et al. (1998). The authors of this study attributed the lack of significant effects of ripping to the fact that they planted the tree rows at right angles to the lines of ripping. This caused some trees to be planted in between the ripped areas where the soil was probably not effectively loosened by the ripping machine.

Mine Soil Chemical Properties and Their Influence on Tree Productivity

A third variable that has important consequences for the establishment of productive forests on reclaimed surface mines is the soil chemical properties associated with a given mine soil. There are several important characteristics of mine soils that directly affect their chemistry. Topsoil replacement and overburden rock type are two of the more important factors controlling mine soil chemical properties. In considering the effects of mine soil chemical properties on tree productivity, it is important to be cognizant of the silvical characteristics of the trees being managed.

Davidson (1986), in a study conducted in Pennsylvania on very acid mine soils (pH range 3.2-3.8), found that pH was significantly related to tree survival for several species, but that by itself, pH was not a reliable estimator of survival. Another study carried out on extremely acid mine soils from Pennsylvania found that of the mine soil properties measured (pH, Ca, Mg, K, P, and three measures of extractable Al), pH accounted for the largest share of the variation in root and shoot growth for paper birch (*Betula papyrifera* Marsh.) and hybrid poplar (McCormick and Amendola, 1983).

Torbert and coworkers (1991) made the case for using acidic (pH 4.8) oxidized brown sandstone for a preferred growth medium for white pine in a case study of successful reforestation with white pine (*Pinus strobus* L.) in West Virginia. In this study, the average tree height after five years was 2m, and some trees were over 3m tall when grown on this type of mine soil.

In a study of the effects of overburden rock type on survival and growth of pitch x loblolly hybrids (*Pinus rigida* P. Mill. X *Pinus taeda* L.), Torbert and coworkers (1990) found an inverse relationship between soil pH and tree volume ($R^2 = 0.86$). This effect was seen in the pH range of 5.7 to 7.1. 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 is noteworthy that pH increased consistently as the proportion of sandstone decreased and as the proportion of siltstone increased. Other pertinent results of this study include the finding that survival was not significantly affected by overburden rock type, but tree volume growth was significantly related to the proportion of sandstone in the mixture ($p> = 0.0001$). Foliar manganese concentration was also significantly related to tree volume.

In a study of mine soil properties associated with white pine growth in the Appalachian coalfields, three of the five variables selected to predict height growth were chemical properties, including electrical conductivity, extractable phosphorous, and exchangeable manganese, with standardized regression coefficients of 0.25, 0.37, and 0.12, respectively (Andrews et al., 1998). With respect to electrical conductivity (EC), McFee et al. (1981) determined that this property, along with water storage, was most frequently related to plant growth for mine soils in southern Indiana. Torbert and coworkers (1988) found that EC was the second most influential variable in determining tree height of white pine in southwestern Virginia mine soils, with a standardized regression coefficient of 0.29.

Nutrient deficiencies are also common on mine spoils. For example, 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).

One treatment commonly used to alleviate certain nutrient deficiencies in mine soils is to apply fertilizers. For instance, Torbert and coworkers (2000) conducted a study to compare the effects of weed control and fertilization on both a pre-SMCRA bench site and a post-SMCRA approximate original contour (AOC) site. The results from this study indicated that on the AOC site, the response to fertilization was a 47-cm difference between treated and control trees at age 5 and a 124cm difference at age 11, though this was not statistically significant. For the bench site, the effects were less pronounced, with a 37-cm difference between fertilized and control trees at age 5 and a 93-cm difference at age 11.

Preve and coworkers (1984) evaluated the effects of mine spoil type, fertilizer (100kg ha^{-1} each of N, P, and K), and mycorrhizae on the survival and growth of white, Virginia, and loblolly pines in a greenhouse study using mine soil from a southwestern Virginia surface mine. The results of this study showed that in sandstone spoil, the addition of fertilizer had no significant effect on seedling emergence, but significantly increased the shoot weight of all three species compared to unfertilized controls. In siltstone-derived spoil, fertilization significantly decreased the emergence and survival of Virginia and loblolly pines and had no significant effect on the shoot weight of any species. Nitrogen fertilization (100kg N ha^{-1} as NH_4NO_3) on mine soil from southwestern Virginia was found to be “important but temporary” by Schoenholtz and coworkers (1992), as it significantly increased first- and second-year survival of pitch x loblolly hybrids but failed to produce significant differences in height or diameter growth.

Kost and coworkers (1998a) found that nitrogen fertilization (168 and 336kg ha^{-1} vs. no nitrogen) significantly increased the survival of silver maple (*Acer saccharinum* L.) and the height growth of green ash after seven years. It was also found that phosphorous fertilization (112kg ha^{-1}), alone or in combination with nitrogen, produced no significant differences in survival or height growth of the four species tested after seven years.

McGill and coworkers (2004) found that fertilization in combination with weed control and tillage resulted in good growth of eight hybrid poplar clones (1.5 to 2.88m of height growth after two years) and that seven of these clones had excellent first-year survival (79 to 99%). In addition to hybrid poplar, these authors found that black cherry (*Prunus serotina* Ehrh.) had an average first-year survival of 92% and a mean height growth of 1.2m after two years of growth under the same treatments.

Influence of Topsoil Replacement on Tree Growth

Replacement of native topsoil or some type of topsoil substitute is believed to have many benefits in terms of survival and growth of trees when compared to cast overburden. One of the main benefits of replaced topsoil is the organic matter content that is lost when cast overburden is selected as the growth medium. This organic matter could be expected to improve infiltration and percolation of water, improve nitrogen availability to trees, increase resistance to compaction, and decrease soil bulk density.

Schoenholtz and coworkers (1992) mixed native topsoil from a mine site in southwestern Virginia with the upper 25 cm of mine spoil in a concrete lysimeter. When compared with the control, the topsoil significantly decreased bulk density of the whole soil and fine soil (<2mm), increased water retention of the fine soil, increased total nitrogen, and increased mineralizable nitrogen. Despite these more favorable conditions, the authors found no significant differences in survival, height growth, diameter growth, or foliar nutrient concentrations for the pitch x loblolly pine hybrids growing in the soils when compared to the control.

Green ash planted on a mine soil in Ohio with replaced topsoil and cast overburden treatments showed that replaced topsoil significantly increased total height of the trees under all herbaceous seeding regimes tested in this experiment (Larson et al., 1995). Survival was significantly lower for green ash planted in replaced topsoil during a drought year when herbaceous seeding was done in August of the previous year with tree planting occurring the following spring. Survival was significantly higher for the topsoiled plots during the following wet years when herbaceous seeding was done in the spring and tree planting occurred the following spring. Otherwise no significant differences existed for survival under the given herbaceous seeding regimes.

Another study of an Ohio mine soil with and without topsoil replacement found significant differences associated with the following soil properties from the topsoil to the cast overburden: increase in pH, decrease in available phosphorous for two different extraction methods, increase in cation exchange capacity, and increase in electrical conductivity (Kost et al., 1998a). This same study showed that the survival and growth of green ash and Austrian pine (*Pinus nigra* Arnold) were significantly higher on the replaced topsoil than on the cast overburden. A similar study conducted by Kost and coworkers (1998b) found that replaced topsoil had nearly twice the density of volunteer trees than was found on cast overburden (181 versus 107 stems ha^{-1} respectively), thus indicating that for native tree species, topsoil may be a preferable growth medium for good establishment. Soil compaction and high levels of soluble salts associated with the cast overburden were cited as reasons for the low number of volunteers on this material compared with the topsoil.

Mine Soil Properties Important to White Pine Growth

Eastern white pine is one of the most extensively planted tree species in reclamation of surface mined lands. The species is also native to the Appalachian coalfield region. White pine's intermediate shade tolerance and ability to grow rapidly even when planted in soils with low fertility give the species its popularity for use in reclamation. As this species has been planted so extensively on mine soils, there has been opportunity to study numerous factors related to white pine productivity on mine soils.

In reviewing research related to tree growth on mine soils, the depth to some type of root-restricting layer is a common deterrent to good tree growth. The type of restriction will be related to either the physical or chemical properties of the mine soil. While these categories can contain numerous specific limitations, the net effect is the same for each, the effect being a decrease in effective rooting depth. This in turn decreases the effective rooting volume of the tree, leading to a decrease in productivity.

Rodrigue and Burger (2004) conducted a study of 14 mine soils in the eastern and midwestern coalfields. Data were collected for selected soil properties as well as for tree growth, and a regression analysis was used to determine mine soil properties most important to tree productivity. In the order of significance to the model, the five variables most important to tree productivity are: base saturation, coarse fragment percentage, available water holding capacity, C horizon total porosity, and soluble salts. The model developed using these five variables explained 52% of the variation in tree productivity. Of the three physical properties of mine soils in this model, both available water holding capacity and C-horizon total porosity were positively related to tree productivity, meaning that an increase in either variable would give an increase in tree productivity. Both of these properties are dictated to an extent by the reclamation process, in that extensive compaction would lead to a decrease in the value of these properties, thus causing a decrease in productivity according to this model.

In another study specifically related to white pine productivity, Torbert and coworkers (1988) developed two models to predict white pine growth from mine soil properties. The first model used the terminal 4-yr increment as the dependent variable as a function of rooting volume index (RVI), where RVI is the depth to a restrictive layer multiplied by the percentage of soil-sized particles in the upper 10cm of soil. In this model, RVI was positively related to tree growth and explained 51% of the variation in tree growth. The second model used total height of the trees as the dependent variable as a function of (in order of increasing importance) RVI, electrical conductivity (defined in the model as a reciprocal transformation), and extractable phosphorous. All variables were positively related to tree growth, and the model explained 53% of the variation in tree growth.

As RVI was the most important variable in both models, it is obvious that increasing the value of this variable should lead to increased tree productivity. As the definition suggests, increasing the depth to a restricting layer, or increasing the percentage of soil-sized particles in the surface 10cm, will increase this variable. This study points out the importance of maximizing the depth to a restricting layer, as increasing the percentage of soil-sized particles may not be possible depending on the availability of spoil materials.

Andrews et al. (1998) developed a model for white pine height growth using two-year terminal height growth as the dependent variable. Rooting depth was the most important variable, with other important variables being electrical conductivity (EC), surface soil P and Mn, and slope. These variables accounted for 48% of the variability in growth. Soil depth had a standardized regression coefficient of 0.35. Height growth was greater on steeper slopes, possibly due to the more compacted nature of level areas as shown by the negative correlation (r = -0.29) between slope percent and bulk density. The most important chemical property affecting growth was EC, with extractable P being the second most important chemical property. Height growth declined when exchangeable Mn levels exceeded 20mg/kg.

CHAPTER III

EFFECTS OF SILVICULTURAL TREATMENTS ON FIRST-YEAR SURVIVAL AND GROWTH OF THREE SPECIES ASSEMBLAGES ON POST-SMCRA RECLAIMED MINED LANDS IN THE APPALACHIAN COALFIELDS

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 often been found to have dense ground covers, compacted soil materials, and unfavorable soil chemical properties associated with them. 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, including hybrid poplar, white pine, and a native hardwood mix. Each species assemblage was treated with a gradient of silvicultural treatments to alleviate the previously mentioned problems associated with post-SMCRA mined land. Treatments included weed control only, weed control plus tillage, and weed control and tillage plus fertilization. Response to treatment in terms of first-year survival and growth was variable by site, with the site in Virginia having the best survival and greatest growth of the three. Hardwood species survived better at all sites than white pine or hybrid poplar. Hardwood survival across treatments was 80%, 85%, and 50% for sites in Virginia, West Virginia, and Ohio, respectively, while white pine survival was 27%, 41%, and 58%, and hybrid poplar survival was 37%, 41%, and 72% for the same sites, respectively. Hybrid poplar height and diameter growth were superior to those of the other species tested, with the height growth of this species reaching 126.6cm after one year in the most intensive treatment at the site in Virginia. In comparison, the greatest height growths of white pine and hardwood were 8.9cm and 7.9cm, respectively. 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. Additionally, the highest level of intensity improved the foliar nutrition of hybrid poplars and appeared to result in more favorable water relations than were found in the intermediate treatment. 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 reforesting post-SMCRA reclaimed mined lands previously reclaimed to grasses.

Key Words: Compaction, ground cover, fertility, reforestation, native hardwoods, white pine, hybrid poplar, reclamation.

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 only attained 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, 1986). Tillage treatments can ameliorate the detrimental effects of compaction. Cleveland and Kjelgren (1994) found that deep tillage (70cm) through ripping doubled the cross-sectional area of low-impedance soil (<1.4MPa of resistance). 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, 1996a). 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, respectively, 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 hybrids (*Pinus rigida* P. Mill. X *Pinus taeda* L.), 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 white pines survived after three years (Larson et al., 1995). White pine is appealing for use in reclamation due to its ability to grow well on soils of low fertility, which are frequently encountered on reclaimed surface mines.

Several hardwood species have also been tested for use in reclaiming surface mined lands. Gorman and Skousen (2003) found excellent survival (90-100%) 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 mountaintop 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 use of hardwoods in reclamation of surface mined land is logical for restoring native vegetation, as surface mined lands in the Appalachian coalfields are primarily forested prior to mining.

Hybrids of the genus *Populus* have been found to grow well on reclaimed surface mines (McGill et al., 2004; Czapowskyj, 1978). These fast-growing species have the potential to provide revenue from timber harvest in as few as 16 years (Davidson, 1979), shade out competing vegetation common to reclaimed surface mines due to rapid canopy growth (Ashby, 1995), and improve soil quality through organic matter cycling and rapid root growth (Ashby and McCarthy, 1990). Additionally, the wood properties of hybrid poplars have been found to exceed industry standards for oriented strand board (Peters et al., 2002), a product that is produced throughout the Appalachian coalfields. Despite these potential benefits, there is a lack of information regarding the response to silvicultural treatment and soil properties on reclaimed surface mined lands.

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

Site Descriptions

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. III.1). The post-mining land use at all sites was hayland 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 5cm to 51cm across the site. Both the topsoil and the spoil had fine textures and low coarse fragment percentages (Tables III.1 and III.2). The topsoil had a lower pH and lower electrical conductivity than the spoil, which was derived from siltstone material. The site has been reclaimed for at least 10 years and had a dense cover of predominantly tall fescue and sericea lespedeza (*Lespedeza cuneata* (Dum.-Cours.) G.Don).

The Nicholas County, West Virginia, site did not have topsoil replaced, and the spoil at this site was derived from shale material throughout the profile. The site had coarse soil textures and high coarse fragment contents (50-60%) throughout the profile

(Tables III.1 and III.2). 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 10 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, with topsoil thicknesses from 0cm to 47cm. This site also had high coarse fragment percentages; however, the spoil typically had more than the topsoil (Tables III.1 and III.2). 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.

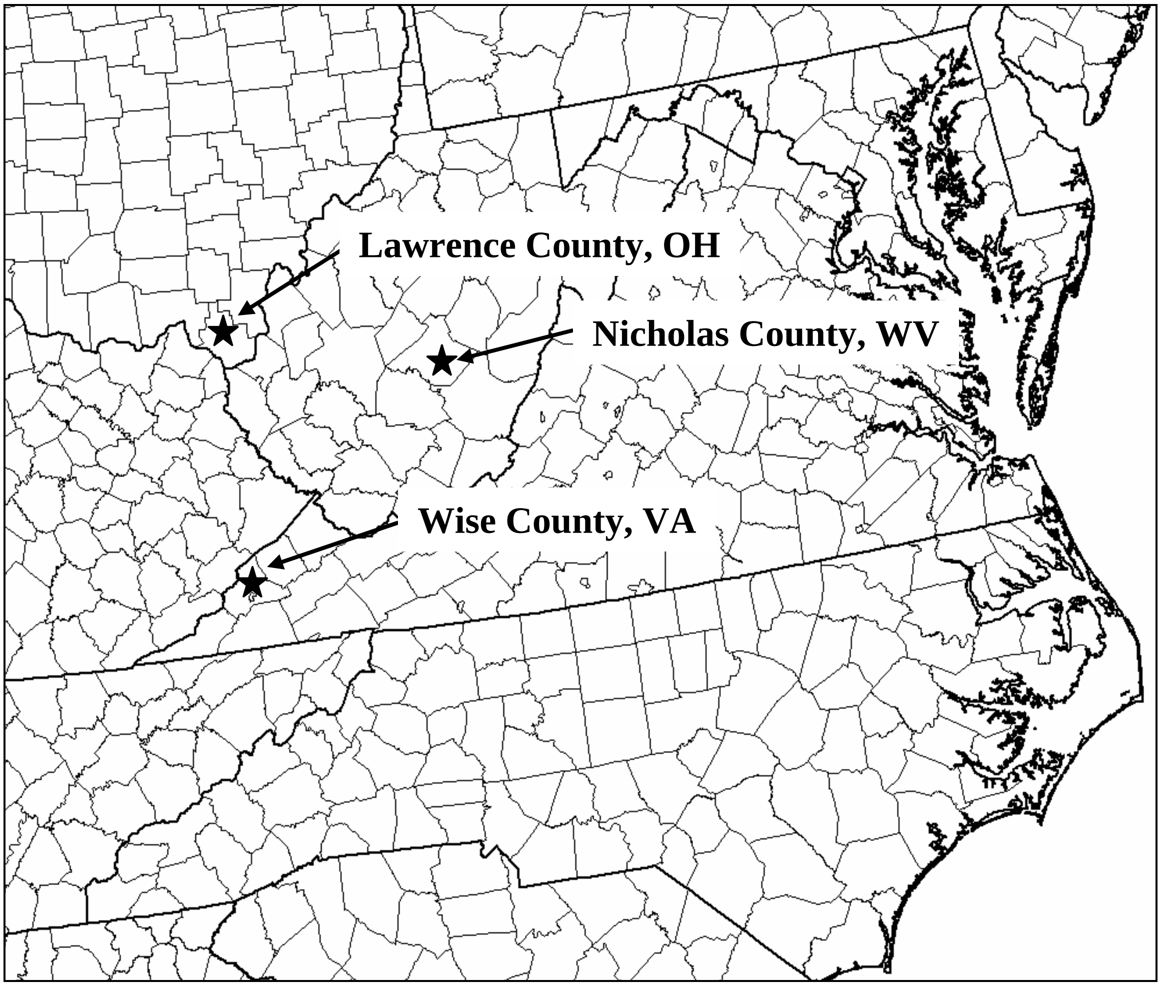

Figure III.1. Geographic location of study sites in the Appalachian coalfield region of the eastern United States.

Table III.1. **Chemical and physical properties for 0-10cm depth of the topsoil of study blocks at research sites in Lawrence County, Ohio, and Wise County, Virginia, and of the spoil material in Nicholas County, West Virginia.**

Site	Block	pH	Electrical Conductivity (dSm^{-1})	CEC ($cmol_c$ kg^{-1})	$NaHCO_3$ Extractable P (mg kg^{-1})	Total N (g kg^{-1})	Coarse Fragments (%)				Texture	Bulk Density (g cm^{-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 oxidized material replaced specifically as topsoil or topsoil substitute.

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

* L=loam; SL=sandy loam.

Table III.2. Chemical and physical properties for spoil materials underlying the topsoil of study blocks at research sites in Lawrence County, Ohio, and Wise County, Virginia, and of the 10-30cm sampling depth of the spoil material in Nicholas County, West Virginia.

Site	Block	pH	Electrical Conductivity (dSm^{-1})	CEC ($cmol_c$ kg^{-1})	$NaHCO_3$ Extractable P ($mg\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	Coarse Fragments (%) Total	Sandstone	Siltstone	Shale	Texture	Bulk Density ($g\ cm^{-3}$)**
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 depths.

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 the mixture of hardwood species varied by site in order to approximate the pre-mining forest condition found in adjacent undisturbed forest (Table III.3). 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 III.3. Species composition and percentage of each species for the mixed hardwood plots at the three study sites.

Species	Percentage		
	Ohio	West Virginia	Virginia
Commercial Hardwoods:			
Northern red oak (*Quercus rubra* L.)	9.6	15.3	10.9
Tulip-poplar (*Liriodendron tulipifera* L.)	9.6	15.3	10.9
Sugar maple (*Acer saccharum* L.)	9.6	15.3	10.9
Black oak (*Q. velutina* Lam.)	9.6	---	---
Chestnut oak (*Q. prinus* L.)	19.2	---	---
Bitternut hickory (*Carya cordiformis* [Wengenh.] K.Koch)	9.6	---	10.9
Scarlet oak (*Q. coccinea* Muenchh.)	9.6	---	---
Red maple (*A. rubrum* L.)	---	15.3	---
White ash (*Fraxinus americana* L.)	---	15.3	10.9
White oak (*Q. alba* L.)	---	---	21.9
Shrub Species:			
Redbud (*Cercis canadensis* L.)	7.7	7.8	7.8
Flowering dogwood (*Cornus florida* L.)	7.7	7.8	7.8
Wash. Hawthorn (*Cretaegus phaenopyrum*)	7.7	7.8	7.8

Plots were blocked within each site based on soil properties (Tables III.1 and III.2). 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 less than 15%.

The weed control treatment used herbicide to reduce existing herbaceous vegetation. In August 2003 a broadcast treatment of glyphosate was applied at a rate of 9.35 l ha^{-1}. Following the glyphosate treatment, a pre-emergent herbicide containing pendimethalin was applied after tree planting in April 2004 at a rate of 4.92 l ha^{-1} 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 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.

Soil Sampling and Analysis

Soil samples were collected from all plots prior to installing any of the silvicultural treatments. Five samples were systematically collected from each plot, four of which were collected at 11m from each plot corner in the direction of the plot center, and the fifth at the center of each plot. Surface soil samples (0-10cm depth) were collected at all plots. If topsoil was present as a cap overlying spoil material, an additional sample of the spoil material underneath the topsoil was collected. If there was no difference in the topsoil material present, the 10-30cm depth was sampled in addition to the surface soil sample. Bulk density of the surface soil was measured at each plot using the excavation method (Blake and Hartge, 1986). Bulk density of the spoil material was measured when it was within 30cm of the soil surface.

All samples were returned to the lab, dried at 50°C for one week, weighed, and sieved to pass a 2mm screen to separate coarse fragments. Coarse fragments were washed with water to remove any fine soil particles, dried, and weighed to determine coarse fragment percentage by weight. Additionally, the percentages of sandstone, siltstone, and shale rock types of each sample were visually estimated as a percentage of the total coarse fragment content.

Soil pH and electrical conductivity were measured on all samples using an AGRI-METER (MYRON L Company) and a 1:2 soil:water mixture. Total soil C and N were determined using an Elementar varioMAX CNS analyzer (Mt. Laurel, NJ). All other laboratory analyses were made on a composite sample of all five samples collected in each plot. All exchangeable cations were extracted with a 1M NH_4OAc solution (USDA, 1996). To determine cation exchange capacity (CEC), exchangeable Al was extracted with 1N KCl and determined titrimetrically (McLean, 1965). The effective CEC was calculated as the sum of NH_4Oac extractable Ca, Mg, K, and NA, and KCl extractable Al (Sumner and Miller, 1996). Particle size analysis was determined using the pipet method (Gee and Bauer, 1986).

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 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 belowground 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^{o} 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. A subsample was then ground using a Wiley mill to pass a 1mm screen. In some instances when samples were small, a coffee grinder was used to grind all the foliage collected.

Hybrid Poplar Tissue Analysis

Tissue samples from the harvested trees in each plot were composited by the following tissue types for nutrient analysis: (1) foliage, (2) stem, and (3) roots. Total C and N were determined using an Elementar varioMAX CNS analyzer (Mt. Laurel, NJ). Samples were dry ashed at 500°C for 24 hours and digested with 6*N* HCl. A SpectroFlame Modula Tabletop inductively coupled plasma spectrophotometer was used to determine elemental concentrations of P, Mg, Ca, and K for all tissue samples and S, B, Cu, Mn, and Zn for foliage samples only.

Hybrid Poplar Moisture Stress Measurements

Water potential of the hybrid poplar seedlings at the site in Nicholas County, West Virginia, was measured using a pressure chamber (PMS Instrument Co. Model 1000 Corvallis, OR) for four consecutive rain-free days (August 16-19, 2004). The initial measurement was made the day after approximately 0.46cm of rain fell in the previous 24 hours and 1.85cm had fallen in the previous 96 hours in nearby Beckley, West Virginia. Three trees from each hybrid poplar plot were measured to obtain average water potential for that plot. Measurements were timed so as to measure the water potential of all trees within a plot at the same time during the afternoon (2:30 to 6:30 p.m.) over the course of the four-day period. Water potential readings were taken immediately after the leaf was excised from the tree.

On the same day on which the plant water stress was measured, soil samples of the surface 30cm were collected from three random locations in each plot. Soil samples were stored in a sealed plastic bag and returned to the lab for determination of gravimetric soil moisture content. Soil sampling preceded water potential sampling and was confined to a time period between 12:30 and 2:00 p.m. Individual plots were sampled at the same time each of the three days (August 17-19, 2004).

Data Analysis

Analysis of variance was used to analyze survival and growth data for differences in survival percentage, height growth, total height, diameter growth, total diameter, volume growth, and total volume as a 3x3x3 factorial random complete block design having three species assemblages, three sites, and three silvicultural treatments (Table III.4). Tree volume was calculated as diameter squared multiplied by tree height. Results for total diameter and total height are presented in Appendix A.

Table III.4. Analysis of variance results for survival and growth parameters for research sites in Lawrence County, Ohio, Nicholas County, West Virginia, and Wise County, Virginia.

Site and Source	Degrees of Freedom	Variable (Pr > F)				
		Survival	Total Height	Height Growth	Diameter Growth	Volume Growth
All Sites:						
Block	2	0.0057	0.0231	0.0076	0.0812	0.8254
Site	2	<0.0001	0.0005	<0.0001	0.0004	<0.0001
Treatment	2	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Site*Treatment	4	0.0097	0.0535	0.0003	0.0036	<0.0001
Species	2	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Site*Species	4	0.0332	0.0021	<0.0001	0.0009	<0.0001
Treatment*Species	4	0.3567	<0.0001	<0.0001	<0.0001	<0.0001
Site*Treatment*Species	8	0.3367	0.1214	<0.0001	0.1146	<0.0001
Model	28	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Error*	52(51)					
Total*	80(79)					
Ohio:						
Block	2	0.1730	0.0432	0.0354	0.1340	0.0881
Treatment	2	0.0005	0.7589	0.5026	0.6628	0.3674
Species	2	0.0197	0.0116	<0.0001	<0.0001	0.0036
Treatment*Species	4	0.3072	0.7321	0.6724	0.1790	0.3126
Model	10	0.0038	0.0640	<0.0001	<0.0001	0.0238
Error*	16 (15)					
Total*	26 (25)					
West Virginia:						
Block	2	0.4873	0.0614	0.0180	0.0713	0.0723
Treatment	2	<0.0001	<0.0001	<0.0001	<0.0001	0.0007
Species	2	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Treatment*Species	4	0.1384	<0.0001	<0.0001	0.0003	0.0026
Model	10	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Error*	16					
Total*	26					
Virginia:						
Block	2	0.0164	0.5926	0.6402	0.9342	0.8400
Treatment	2	0.3422	<0.0001	<0.0001	<0.0001	<0.0001
Species	2	0.0006	<0.0001	<0.0001	<0.0001	<0.0001
Treatment*Species	4	0.4849	<0.0001	<0.0001	<0.0001	<0.0001
Model	10	0.0060	<0.0001	<0.0001	<0.0001	<0.0001
Error*	16					
Total*	26					

*Degrees of freedom in parentheses are for total height and growth variables only. Zero survival in one study block caused the loss of one degree of freedom from all growth variables.

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).

Following the overall analysis, separate analyses were performed on each of the groups of hardwoods that were planted (Table III.3). The same species were included in the HW1 and shrub groups at each site, while the species in the HW2 group varied by site. These data were analyzed in the same manner as the overall analysis, except that the three groups of hardwoods replaced the three species assemblages used in the overall study and are presented in Appendix B.

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). Similarly, nutrient concentration data from tissue samples were analyzed for differences among silvicultural treatments by tissue type. Non-normal and heteroscedastic data were transformed using the inverse function prior to analysis of variance. Data on soil moisture content and plant water potential were analyzed as a split-plot design with silvicultural treatment as the whole plot and date as the split plots (Gomez and Gomez, 1984).

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, with the exception of the site by treatment interaction for total height, which had a p-value of 0.0535 (Table III.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 III.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 III.5). At the West Virginia (WV) site, survival in WC+T was significantly higher than in 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 III.5) and the rate was significantly higher than that of all other species at all three sites except for hybrid poplar in OH. 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 III.5).

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

Site and Treatment	Species Group			Treatment Mean
	HW	HP	WP	
Ohio:				
WC	60	49	45	51 x**
WC+T	72	45	29	49 x
WC+T+F	18	17	6	14 y
Species Mean	50 A*	37 AB	27 B	38
West Virginia:				
WC	78	32	41	51 x
WC+T	94	62	50	69 y
WC+T+F	68	27	33	43 x
Species Mean	80 A	41 B	41 B	54
Virginia:				
WC	81	79	53	71 x
WC+T	90	70	70	77 x
WC+T+F	84	67	50	67 x
Species Mean	85 A	72 B	58 B	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 $P<0.05$.

Total Height

At the site in OH, there were no significant differences among species or treatments, as shown by the insignificant model term for this site (Table III.4). Total height ranged from 29.7cm in WC to 33.4cm in WC+T to 37.6cm in WC+T+F (Table III.6). Total heights of hybrid poplar, white pine, and hardwoods were 45.6cm, 23.3cm, and 30.1cm for these species, respectively.

Table III.6. Total tree height (cm) for three species groups planted on post-SMCRA reclaimed surface mined lands in Lawrence County, Ohio, Nicholas County, West Virginia, and Wise County, Virginia, as affected by silvicultural treatments.

Site and Treatment	Species Group			Treatment Mean
	HW	HP	WP	
Ohio:				
WC	30.8	35.8	22.4	29.7 x**
WC+T	25.0	50.3	24.7	33.4 x
WC+T+F	34.4	50.8	22.6	37.6 x
Species Mean	30.1 A*	45.6 A	23.3 A	33.4
West Virginia:				
WC	32.4 A x	22.4 B x	25.2 C x	26.6
WC+T	38.6 A x	60.2 B y	28.2 C y	42.3
WC+T+F	36.5 A x	57.6 B y	22.9 C x	39.0
Species Mean	35.8	46.7	25.4	36.0
Virginia:				
WC	33.1 AB x	40.9 A x	23.5 B x	32.5
WC+T	37.0 A x	65.4 B x	25.0 C x	42.4
WC+T+F	40.6 A x	126.6 B y	22.6 C x	63.3
Species Mean	36.9	77.6	23.7	46.1

*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 WV, there was a significant interaction between species groups and silvicultural treatments for total height (Table III.4). Hybrid poplar was the shortest (22.4cm) in WC compared to hardwood (32.4cm) and white pine (25.2cm). In contrast, hybrid poplar was taller in both WC+T (60.2cm) and WC+T+F (57.6cm) compared to hardwood and white pine in comparable treatments, where total heights ranged from 36.5cm to 38.6cm for hardwood and from 22.9cm to 28.2cm for white pine.

There was also a significant interaction between species groups and silvicultural treatment in VA (Table III.4). There was no difference among the silvicultural treatments for hardwood or white pine, where total height ranged from 22.6cm to 25.0cm for white pine and from 33.1cm to 40.6cm for hardwood. However, hybrid poplar was significantly taller in WC+T (65.4cm) and WC+T+F (126.6cm) than both hardwood and white pine. Hybrid poplar was significantly taller than white pine in WC, with average total heights of 40.9cm versus 23.5cm, respectively, but it was not taller than hardwood (33.1cm).

Height Growth

Analysis by site revealed that the species by treatment interaction was not significant in OH (Table III.4) and that there were no treatment effects at this site (Table III.7). Height growth of hybrid poplar was several times higher than hardwood and white pine in OH (45.6cm versus -2.3cm and 6.0cm, respectively). Seedlings in the hardwood group had died back; thus, they were 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 III.7).

Table III.7. Average height growth (cm) for three species groups planted on post-SMCRA reclaimed surface mined lands in Lawrence County, Ohio, Nicholas County, West Virginia, and Wise County, Virginia, as affected by silvicultural treatments.

Site and Treatment	Species Group			Treatment Mean
	HW	HP	WP	
Ohio:				
WC	-1.0	35.8	5.2	13.3 x**
WC+T	-3.7	50.3	5.4	17.4 x
WC+T+F	-2.3	50.8	7.9	20.2 x
Species Mean	-2.3 A*	45.6 B	6.0 A	16.8
West Virginia:				
WC	-1.4 A x	22.4 B x	5.5 A x	8.8
WC+T	3.2 A xy	60.2 B y	8.9 A x	24.1
WC+T+F	7.7 Ay	57.6 B y	5.8 A x	23.7
Species Mean	3.2	46.7	6.7	18.9
Virginia:				
WC	3.7 A x	40.9 B x	6.0 A x	16.9
WC+T	3.9 A x	65.4 B x	5.9 A x	25.1
WC+T+F	7.9 A y	126.6 B y	5.5 A 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 WV, the species by silvicultural treatment interaction was significant (Table III.4), and height growth for hardwood was greater in WC+T+F than in WC (Table III.7). 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).

In VA, there was also significant treatment by species interaction (Table III.4). Height growth was greater in WC+T+F than in the other treatments for both hardwood and hybrid poplar (Table III.7). The differences in height growth were more pronounced for hybrid poplar (126.6cm in WC+T+F versus 40.9cm and 65.4cm for WC and WC+T, respectively) (Table III.7).

Diameter Growth

There was no interaction between species and silvicultural treatment (Table III.4), nor were there any silvicultural treatment effects on diameter growth at the OH site (Table III.8). However, diameter growth of hybrid poplar (5.7mm) was significantly greater than diameter growth of hardwood or white pine, which both averaged 0.7mm.

A significant interaction between species group and silvicultural treatment occurred in WV (Table III.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 III.8). 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 III.8), which also had a significant species by silvicultural treatment interaction (Table III.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.

Table III.8. Average diameter growth (mm) for three species groups planted on post-SMCRA reclaimed surface mined lands in Lawrence County, Ohio, Nicholas County, West Virginia, and Wise County, Virginia, as affected by silvicultural treatments.

Site and Treatment	Species Group HW	HP	WP	Treatment Mean
Ohio:				
WC	0.9	4.1	0.9	2.0 x**
WC+T	0.8	5.5	0.5	2.3 x
WC+T+F	0.3	7.4	0.7	3.1 x
Species Mean	0.7 A*	5.7 B	0.7 A	2.4
West Virginia:				
WC	0.9 A x	3.1 B x	0.5 C x	1.5
WC+T	1.4 A x	7.0 B y	0.7 A x	3.0
WC+T+F	1.8 A x	7.5 B y	0.9 A x	3.4
Species Mean	1.4	5.9	0.7	2.6
Virginia:				
WC	0.8 A x	4.9 B x	0.6 A x	2.1
WC+T	1.4 A x	7.0 B x	0.6 A x	3.0
WC+T+F	2.1 A x	13.9 B y	0.7 A 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 $P<0.05$.

Volume Growth

The interaction between species groups and silvicultural treatments was not significant at the study site in OH for volume growth (Table III.4). Volume growth of hybrid poplar (30.7cm^3) was significantly greater than the volume growth of either hardwood (2.1cm^3) or white pine (2.3cm^3), which were not different from one another (Figure III.2a). There were no significant effects of silvicultural treatment on volume growth in OH, although volume growth more than tripled from 6.1cm^3 in the WC treatment to 21.0cm^3 in the WC+T+F treatment at this site (Figure III.2b).

In WV, there was an interaction between species group and silvicultural treatment (Table III.4). The volume growth response was larger in hybrid poplar, which increased from 2.8cm^3 to 43.3cm^3, than in WP, which increased from 2.3cm^3 to 4.2cm^3 (Figure III.2c). As a result of the large increase in the WC+T treatment, volume growth in hybrid poplar was significantly greater than volume growth in either hardwood or white pine for this treatment (Figure III.2d). There was no additional increase in volume growth in WV in the WC+T+F treatment for either hybrid poplar or white pine. Silvicultural treatment had no impact on the growth of the hardwood species group in WV. Volume growth in the WC treatment was not different among the species groups, which averaged 2.3cm^3 in both hardwood and white pine and 2.8cm^3 in hybrid poplar (Figure III.2d). Volume growth in both hybrid poplar and white pine increased as silvicultural intensity increased from WC to WC+T.

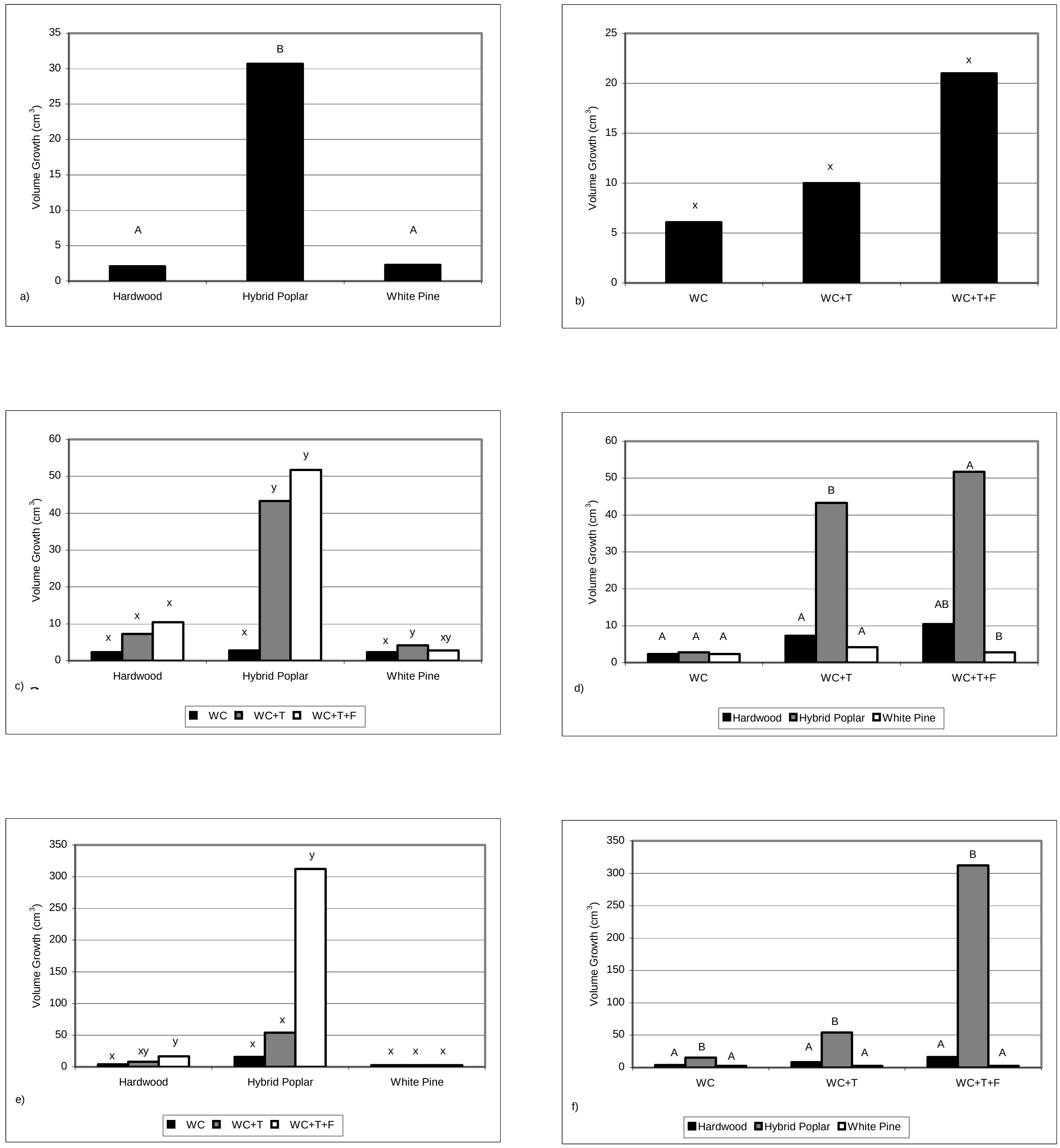

Figure III.2. Average volume growth (cm^3) for three species groups planted on post-SMCRA reclaimed surface mined lands in: (a-b) Lawrence County, Ohio (main effects only), (c-d) Nicholas County, West Virginia, and (e-f) Wise County, Virginia, as affected by silvicultural treatments.

At the site in VA, there was also a significant species by silvicultural treatment interaction for volume growth (Table III.4). Volume growth of hybrid poplar (15.6cm^3) was greater than volume growth of either hardwood (4.0cm^3) or WP (2.8cm^3) in the WC treatment (Figure III.2e). Volume growth in both hardwood and hybrid poplar increased in response to increasing silvicultural input. In the WC+T+F treatment, volume growth increased to 16.5cm^3 for hardwood and 312.1cm^3 for hybrid poplar (Figure III.2f). In contrast, volume growth in white pine was not affected by silvicultural treatment. Volume growth of hybrid poplar remained significantly greater than volume growth of hardwood or white pine as silvicultural intensity increased.

Hybrid Poplar Biomass

Total plant biomass of hybrid poplar at the site in WV increased significantly with the intensity of silvicultural input (P=0.0002) (Figure III.3). 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 (Figure III.3). 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 than 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).

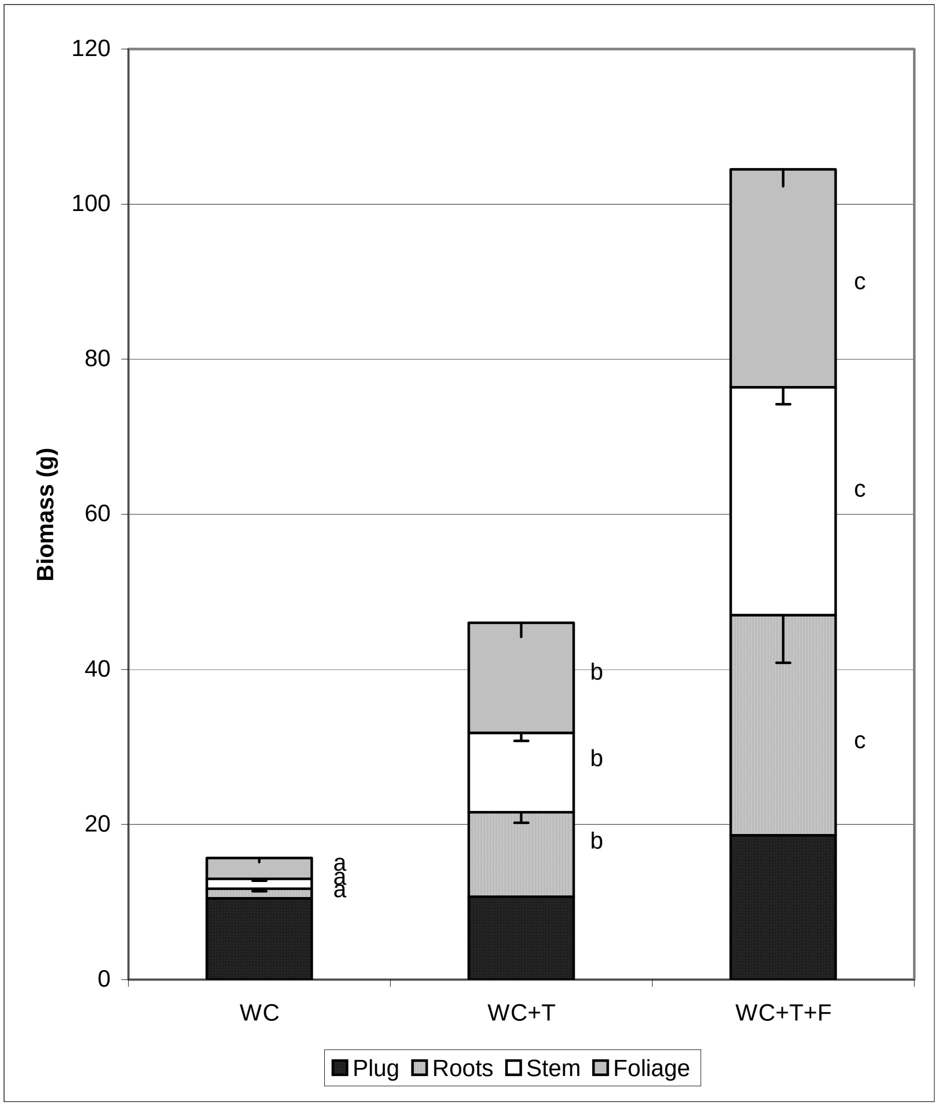

Figure III.3. Hybrid poplar biomass by plant part and treatment for the study site in Nicholas County, West Virginia. Letters beside segments indicate significant differences at the $P < 0.05$ level among treatments for that particular segment.

Hybrid Poplar Tissue Analysis

Foliar nutrient concentrations were significantly higher for N, P, and Mn in the WC+T+F treatment compared to the other two treatments (Table III.9). Foliar N in the WC+T+F treatment was 32.58g kg^{-1} compared to 24.16g kg^{-1} and 26.09g kg^{-1} in the WC and WC+T treatments, respectively. Foliar K in the WC+T+F (17.28g kg^{-1}) treatment was only significantly higher than in the WC treatment (14.19g kg^{-1}). There were no differences among silvicultural treatments for any other nutrients.

For stem tissue, N concentration in the WC+T+F treatment (8.33g kg^{-1}) was significantly greater than in the WC treatment (7.16g kg^{-1}) (Table III.9). No other significant differences were found for nutrient concentrations in stem tissue. The concentration of N in the root tissue was also significantly higher for the WC+T+F treatment compared to the WC+T treatment (11.26g kg^{-1} versus 7.88g kg^{-1}). This was the only significant difference in root tissue nutrient concentrations.

Table III.9. Macro- and micronutrient concentrations by tissue type and silvicultural treatment for hybrid poplar growing at the research site in Nicholas County, West Virginia.

Tissue Type and Treatment	Macronutrients (g kg^{-1})					Micronutrients (mg kg^{-1})				
	N	P	K	Mg	Ca	S	Zn	B	Cu	Mn
Foliage:										
WC	24.16 x*	1.98 x	14.19 x	4.60 x	12.14 x	3.92 x	84.30 x	30.04 x	8.95 x	161.17 x
WC+T	26.09 x	1.93 x	15.89 xy	4.86 x	12.26 x	4.82 x	92.21 x	26.61 x	9.71 x	134.44 x
WC+T+F	32.58 y	2.32 y	17.28 y	5.11 x	11.95 x	4.42 x	84.94 x	46.98 x	10.92 x	309.97 y
Stem:										
WC	7.16 x	0.37 x	2.76 x	0.51 x	1.37 x					
WC+T	7.40 xy	0.24 x	2.14 x	0.51 x	1.25 x					
WC+T+F	8.33 y	0.25 x	1.71 x	0.41 x	0.98 x					
Root:										
WC	9.38 xy	1.06 x	8.68 x	1.80 x	6.30 x					
WC+T	7.88 x	0.95 x	10.65 x	1.79 x	7.28 x					
WC+T+F	11.26 y	1.21 x	10.63 x	2.01 x	7.55 x					

* x,y,z - For a given plant part, values within columns with the same letter are not significantly different at $P<0.5$.

Hybrid Poplar Moisture Stress

There was a statistically significant decrease in soil moisture over the three-day measurement period (Table III.10). Soil moisture decreased from 0.15kg kg^{-1} on August 17 to 0.12kg kg^{-1} on August 19. Soil moisture content in the WC treatment was significantly greater than moisture content in the WC+T treatment only.

Table III.10. Gravimetric soil moisture and water potential for hybrid poplar growing at the research site in Nicholas County, West Virginia, over four rain-free days by silvicultural treatment.

Treatment	Aug. 16	Aug. 17	Aug. 18	Aug. 19	Treatment Average
	Gravimetric Soil Moisture (kg kg^{-1})				
WC	.	0.16	0.15	0.12	0.14 x**
WC+T	.	0.14	0.13	0.12	0.13 y
WC+T+F	.	0.15	0.12	0.12	0.13 xy
Date average	.	0.15 A*	0.13 B	0.12 C	0.13
	Water Potential (MPa)				
WC	-1.30 A x	-1.66 B x	-1.89 B x	-1.62 AB x	-1.62
WC+T	-1.32 A x	-1.72 AB x	-1.90 BC x	-2.30 C y	-1.81
WC+T+F	-1.17 A x	-1.97 B y	-1.97 B x	-1.78 B xy	-1.72
Date average	-1.26	-1.78	-1.92	-1.90	-1.72

*A,B,C- values within rows with the same letter are not significantly different at $P<0.05$.
**x,y,z - values within columns with the same letter are not significantly different at $P<0.5$.

There were no differences in leaf water potential among the three treatments on Aug. 16, when leaf water potentials ranged from -1.17MPa in the WC+T+F treatment to -1.32MPa in the WC+T treatment to -1.30MPa in the WC treatment. Leaf water potential decreased from Aug. 16 to Aug. 17 in all three treatments, with the largest decrease occurring in the WC+T+F treatment. On Aug. 17, leaf water potential in the WC+T+F treatment declined to -1.97MPa, which was significantly less than leaf water potential in the WC+T treatment (-1.72MPa) or the WC treatment (-1.66MPa). Leaf water potential stabilized in the WC+T+F treatment, but continued to decline over time in the other two treatments, dropping to -1.89MPa in the WC treatment and –1.90MPa in the WC+T treatment on Aug. 18. Leaf water potential increased on Aug. 19 in the WC and the WC+T+F treatments, but continued to decline rapidly in the WC+T treatment, where it reached -2.30MPa, which was significantly different than leaf water potential in the WC treatment.

Discussion

Site Effects

Replaced topsoil has been shown to perform better as a growth medium for trees (Larson, 1995; Kost et al., 1998a) and to have more favorable soil physical and chemical properties (Schoenholtz et al., 1992) compared to cast overburden. Despite having topsoil replaced over the entire site, both survival and growth were lower in OH than at either of the other sites. Topsoil at this site had a loam texture, but was underlain by a compacted (1.70g cm^3) siltstone-derived spoil, which had a silty clay loam texture and no soil structure. This combination of physical properties associated with the spoil at this site has been shown to perch water (Kozlowski, 1999). Poor drainage was further evidenced by areas of standing water and hydrophytic vegetation that were frequently found across the site. The underlying spoil materials also had unfavorable chemical properties for good survival and growth. For example, both pH and electrical conductivity (EC), at levels of 6.9 and 0.47dS m^{-1}, respectively, are within or near the ranges reported by Torbert and coworkers (1994) as negatively affecting tree growth (pH > 6.0 and EC > 0.50dS m^{-1}).

Another explanation of the poor survival and growth of all species in OH could be that although weed control was carried out uniformly at all sites, the site in OH was observed to have the densest cover of weeds throughout the growing season, hence excessive competition for light water and nutrients could have decreased survival and growth at this site (Nyland, 2002).

The site in WV did not have topsoil replaced. The shale-derived overburden at this site proved to be better than the replaced topsoil and underlying siltstone-derived spoil in OH for the treatments and species used. Although bulk density at this site ($1.68 g.cm^{-3}$) was similar to that in OH, the WV site likely had better water relations due to sandy loam textures throughout the profile and coarse fragment percentages in excess of 50%. Compaction was evident, however, as survival increased significantly as a result of tillage, whereas in OH and VA survival was not significantly affected by tillage. Further evidence that this site was compacted is indicated by the fact that WC+T tripled the height growth and total plant biomass of hybrid poplar compared to that found in the WC treatment at this site. Another explanation of better survival and growth in WV when compared to OH would be that the inherent soil N and P levels were nearly double those found at any of the other sites. Kost and coworkers (1998a) found that improving soil N status through fertilization significantly increased the survival of silver maple and the height growth of green ash after seven years.

The oxidized sandstone spoil that was characteristic of the site in VA proved to be superior to the soils at the other sites in terms of potential for good survival and growth for the species and treatments used. Survival across species and treatments at this site averaged 72%, compared with 54% and 38% for WV and OH, respectively. Similar trends were evident for all growth measures. This oxidized sandstone material has been shown to be a superior growth medium for trees (Torbert et al., 1990; Torbert et al., 1991). Reasons cited by these authors for using this specific material include chemical properties similar to the native soils on which these trees grow in comparison to unoxidized materials such as lower pH and lower soluble salt levels. This material also has improved physical properties compared to material derived from finer textured rock types. Oxidized sandstone has also been shown to weather to soil-sized particles faster than unoxidized siltstone spoils (Hearing et al., 1993), thereby increasing water holding capacity and nutrient availability at a more rapid rate than would be found in the other materials.

Silvicultural Treatment Effects

Weed control on reclaimed surface mines has been shown by numerous researchers to be necessary for adequate establishment of forests. For example, on a surface mine in Indiana, Andersen and coworkers (1989) found that black walnut and northern red oak survival increased from 4% and 1% respectively with no ground cover control to 66% and 48% respectively with ground cover control. Torbert et al. (2000) found that after five years, average tree height growth for three pine species was 66cm greater in plots where ground cover was controlled than in plots where it was not. The same study reported that after 11 years, the difference in average tree height increased to 158cm, which shows that ground cover control has effects lasting for more than a few years after the trees become established.

Although weed control is necessary, this treatment alone may not provide adequate survival or growth if unfavorable soil physical or chemical properties exist. For example, compacted layers are common on surface mines (Daniels and Zipper, 1997; Bussler et al., 1984) despite the fact that many of these mine soils are over 50% coarse fragments. In our study, tillage to alleviate soil compaction coupled with weed control (WC+T) generally resulted in better survival and growth compared with the WC treatment. This was especially true in WV, where compaction likely limited tree survival and growth. In VA and in OH there was no response to WC+T, and in the case of white pine in OH, WC+T decreased survival considerably, though this decrease was not significant.

Tillage in addition to weed control at the WV site significantly increased the survival of all species and nearly tripled height growth and total plant biomass of hybrid poplar. Tillage has been shown to ameliorate the poor physical properties that are common on reclaimed surface mined land. The net effect of ripping mine soil is a lower bulk density, which translates into lower soil strength, better aeration, and a better rooting environment for trees. Cleveland and Kjelgren (1994) found that deep tilling a mine soil to a depth of 0.7m with a vibrating shank doubled the cross-sectional area of low-impedance soil from 0.29 to 0.58 m^2. Tillage has also been shown to improve survival and growth of trees on reclaimed mined land. For instance, Ashby (1997) found that the mean height of 16 different tree species combined as well as all species individually (with the exception of *Liquidambar styraciflua*) in all five years of the study showed significant increases in height growth as a result of ripping the soil to a depth of 1.2m. 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.

One explanation for the failure of the tillage treatment to increase survival or growth consistently, despite the high bulk density structureless spoils in OH, could be that tillage would have brought the roots into contact with the spoil, which would have been detrimental to survival and growth in terms of the chemical properties associated with the spoil. 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, ripping them when soil moisture content was high would have simply sliced through the soil rather than shatter it (Unger and Cassel, 1991). It is likely that the lack of response to tillage in OH was that it failed to reduce the bulk density and improve aeration through shattering at this site.

Fertilization in addition to weed control and tillage provided mixed results in this study. One trend that was clearly evident with this treatment was a reduction in survival. This reduction was most pronounced in WV and OH, where WC+T+F reduced survival to levels significantly below that found in WC+T in WV, and below both WC and WC+T in OH. 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. 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. The diammonium phosphate and muriate of potash fertilizers used in this treatment pose moderate and high salt hazards, respectively (Brady and Weil, 2002). In a study of aspen establishment and growth, van den Driessche and coworkers (2003) found that fertilization without irrigation led to a 17% decrease in survival compared with the control. These authors cited moisture stress due to the use of soluble fertilizers as the reason for the decrease in survival. For a detailed review of salt effects in forest trees, see Allen and coworkers (1994). 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, with soluble salt levels near the range of 0.50dS m^{-1}, which was found to be near reported ranges where tree growth was negatively affected (Torbert et al., 1994). Electrical conductivity in both the surface and subsurface layers at the sites in WV and VA had values less than this same reported range (0.50dS m^{-1}).

The growth of hardwood species in WV and both hardwood and hybrid poplar in VA increased as a result of fertilization. Some hardwood species have been shown to be more tolerant of alkaline soils with relatively high levels of soluble salts compared to white pine, and therefore would not be as affected by fertilization-induced salt effects. Kost and coworkers (1998a) found that on cast overburden with high levels of soluble salts, green ash (*Fraxinus pennsylvanica* Marsh.) had 91% survival after seven years, whereas white pine survival in the same material was only 1%. Looking at the hybrid poplar response, WC+T+F in VA produced the largest response to treatment of all combinations of sites, treatments, and species used in this study, as first-year height growth averaged 126.6cm with a survival rate of 67%. As 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) this response to fertilization at this site is logical. 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 due to less competition for the added soil nutrients. Similar results were found by McGill and coworkers (2004) for hybrid poplar on surface mines in central WV. In their study of 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% (compared to 72% for the WC+T+F treatment in our study).

Species Effects

Both hardwood and white pine grew little over the course of the first year. White pine is known for its slow growth during its initial years of establishment (Wendel and Smith, 1990; Lancaster and Leak, 1978). Chaney and coworkers (1995) found that red oak and black walnut grew at a rate of 10cm yr^{-1} after 12 years on reclaimed mined land where weeds had been controlled chemically, which, despite being greater than the highest growth rate for hardwoods in this study (7.9cm), is still slow in comparison to hybrid poplar. Hardwoods, however, had survival rates (60% to 94% in WC and WC+T) that were higher than those observed for white pine, which indicate that if weed control can be continued, an adequately stocked stand of hardwood trees has the potential to develop. The white pine survival rates observed (27% in OH, 41% in WV, and 58% in VA across treatments) are low enough that even if weed control were continued, the final stand would likely be understocked without replanting. Several cases of good hardwood survival have been reported. 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). McGill and coworkers (2004) found excellent survival (>90%) for the two hardwood species used (white ash and black cherry), whereas low survival was found for white pine (48%) at the one site at which this species was planted.

Growth of hybrid poplar was superior to that of any other species assemblage tested at any level of silvicultural treatment at all sites. There was a large response to WC+T+F for hybrid poplar in VA, where total stem volumes averaged 312.1cm^3 and 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).

The evaluation of hybrid poplar biomass, foliar nutrition, and water relations at the WV site revealed that this species responded well to silvicultural treatment. At this site, hybrid poplar had significantly higher root, stem, foliage, and total plant biomass as silvicultural intensity levels increased from WC to WC+T to WC+T+F. In terms of N, P, and K nutrient levels in hybrid poplar foliage, Stanturf and coworkers (2001) recommend 2% to 3% foliar N as a critical level below which fertilization should be considered and noted that growth increases are common above this range. Our results show that this level was maintained in all treatments, with the level of the WC+T+F treatment exceeding the previously mentioned range (approximately 3.3%). These same authors recommended foliar N to foliar P and foliar K ratios of 100:11 and 100:48 for these elements, respectively. Foliar P failed to meet this level in all treatments, though the concentration was significantly higher in the WC+T+F treatment compared to the other treatments, while foliar K exceeded these levels in all treatments and was highest in WC+T+F. The WC+T+F treatment appeared to improve water relations compared to WC+T near the end of the growing season as evidenced by the more favorable leaf water potential (-1.78MPa) at the end of a four-day period without measurable precipitation compared to the WC+T treatment (-2.30MPa). Harvey and van den Driessche (1997) found that N fertilization alone decreased drought resistance in *Populus trichocarpa* Torr. & Gray, but fertilization with P alone increased drought resistance. They suggest that fertilization with N and P, as was used in our study, may allow good growth without leading to poor water relations.

Conclusions

Successful reforestation of surface mined land that has been reclaimed to grasses involves selecting sites with suitable soil characteristics for good establishment and growth of trees. Soil conditions can be altered through silvicultural treatments to ameliorate certain conditions that will limit tree establishment and growth on these lands. The results of our investigation show the importance of recognizing the interactions among site conditions, silvicultural treatments, and tree species, as there were numerous interactions among these factors that ranged from reforestation failure to success. Several conclusions can be drawn from the results of this investigation, including:

1. 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 topsoils in conjunction with siltstone-derived alkaline spoils, other treatments and/or species may be needed to ensure good establishment and growth of forest stands.

2. Weed control plus tillage may be the optimum treatment for establishment of hardwoods and white pine, as any increased growth resulting from the fertilization treatment applied in this study may not offset the decreased survival that accompanied the fertilization.
3. White pine and hardwood species grew little over the course of the first growing season as mean heights ranged from 25cm to 40cm for hardwoods and from 20cm to 30cm for white pine. Continued weed control will be needed to ensure the trees do not succumb to the competing vegetation.
4. 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.
5. Hybrid poplar appears to have good potential for reverting post-SMCRA reclaimed mined lands that currently support grasses back to forests, as this species had good growth with 50cm 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.
6. 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, with WC+T+F trees also showing improved foliar nutrition compared to WC and WC+T, and improved water relations compared to the WC+T treatment.

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CHAPTER IV

GROWTH OF A THINNED WHITE PINE STAND GROWING ON A RECLAIMED SURFACE MINE IN SOUTHWESTERN VIRGINIA

Abstract

Little information exists on the productive potential of forests growing on reclaimed mined land and the response of these forests to intermediate stand treatments such as thinning. A thinning study was established as a random complete block design to evaluate the response to thinning of a 26-year-old white pine stand growing on a reclaimed surface mine in southwest Virginia. Stand parameters were projected to age 30 using a stand table projection. Site index of the stand was found to be 32.3m at base age 50 years. Thinning rapidly increased the diameter growth of the residual trees to 0.84cm yr^{-1} compared to 0.58cm yr^{-1} for the unthinned treatment; however, at age 26, there was no difference in volume or value per hectare. At age 30, the unthinned treatment had a volume of 457.1m^3 ha^{-1} but was only worth \$8807ha^{-1}, while the thinned treatment was projected to have 465.8m^3 ha^{-1}, which was worth \$11265ha^{-1} due to a larger percentage of the volume in sawtimber size classes. These results indicate that commercial forestry is a viable alternative for reclamation of surface mined lands and that stands growing on reclaimed mined land can respond well to intermediate stand treatments.

Key Words: Reclamation, White Pine, Thinning, Productivity, Volume Growth

Introduction

The Appalachian coal-producing region of the eastern United States is predominantly forested prior to surface mining. The process of surface mining removes these forests and the native soils that support them. As these lands were primarily forested prior to mining, a logical post-mining land use would be return of the land to commercial forestry uses. Several cases of viable commercial forests have been documented. For example, Rodrigue and coworkers (2002) found that forests on 13 of the 14 mined sites studied in the eastern and midwestern coal-producing regions were equally or more productive than adjacent non-mined forests. Davidson (1979) found that after 10 years of growth on a surface mine in Pennsylvania, hybrid poplar averaged 25.4cm in diameter breast height and 19.8m in height. Annual volume growth in the stand was about 17.9m^3 ha^{-1} yr^{-1}.

Eastern white pine has been planted extensively on surface mined lands because of its ability to grow rapidly on low-fertility soils that commonly exist after surface mining. Ashby (1996b) found that white pine had an average height of 21m and an average diameter of 29.0cm at age 47 on two mined sites in southern Illinois. In a reforestation case study on a surface mine in West Virginia, Torbert and coworkers (1991) found that after five years white pine height was 2.7m, which, based on site index curves for white pine in the southern Appalachians, should mean that these trees will reach heights greater than 30.5m by age 50. These growth rates are comparable to the growth of white pine on native soils in the southern Appalachians (Doolittle, 1958).

Little information is currently available regarding the response of forests growing on surface mined lands to intermediate stand treatments such as thinning. The purpose of this study is to report the productivity and response to thinning in terms of volume and value of a 26-year-old white pine stand located on a surface mine in Wise County, Virginia.

Methods

The study site was a white pine plantation located on a surface mine in Wise County, Virginia, reclaimed prior to the passage of the Surface Mining Control and Reclamation Act of 1977. Following surface mining of the coal, the overburden rock was simply pushed back across the site, creating a bench and highwall profile. The resulting spoil at this site was a mixture of sandstone, siltstone, and coal-derived materials. The stand was planted in 1978, and in 1996 a thinning study was installed. In 1996, at age 17, the stand contained 1438stems ha^{-1} with $30.1m^2$ ha^{-1} of basal area. Three paired blocks of 0.02-ha plots were established in the stand prior to thinning. One plot in each block was randomly selected for thinning, and the basal area was reduced to $20.7m^2$ ha^{-1}, leaving a final stand density of 652stems ha^{-1}. The second plot in each pair was left as a control and was not thinned. All plots were measured in 1996 for total height and diameter at breast height for all living white pines. Five randomly selected dominant or co-dominant trees from each plot were measured annually to evaluate the change in diameter increment due to thinning over time. Height and diameter of all trees in the plots were re-measured in 2004, nine years after the thinning, when the stand was 26 years old.

Site index was calculated based on the average height of trees in the upper quartile of total height to approximate dominant and co-dominant trees using site index equations for white pine in the southern Appalachians (Beck, 1971). Cubic foot volumes to a 10cm top d.i.b. were calculated using volume equations for white pine in the southern

Appalachians (Vimmerstedt, 1962). Board foot volumes to a 15cm top d.i.b. were calculated using equations for white pine plantations in southeastern Ohio (Dale et al., 1989). Minimum diameter for sawtimber was set at 30cm. For pulpwood, cubic meter volumes were converted to cubic foot volumes and then to tons of pulpwood using a conversion factor of 35.9ft^3 ton^{-1}. Stumpage prices for sawtimber and pulpwood (Timber Mart-South, 2004) were applied to stand volume estimates to obtain stand value estimates for thinned and unthinned treatments. Stand parameters measured at age 26 were projected to age 30 using a stand table projection (Avery and Burkhart, 2002). Total tree height at age 30 was predicted from site index equations (Beck, 1971) based on the site index of each tree at age 26.

Data from the 2005 inventory were analyzed for differences in dbh, basal area per hectare, trees per hectare, volume per hectare, volume per tree, proportion of volume in sawtimber, and value per hectare between treatments using a random complete block design with three blocks and two treatments per block. Analysis of variance was used to detect statistically significant differences between treatments. Proportion data were transformed using arcsine transformation prior to analysis of variance. The annual diameter measurements were analyzed using a repeated measures mixed model procedure to test the statistical significance of change in diameter increment with respect to thinning treatment over time. Transformation of the response variable using the natural log function was used to satisfy model assumptions. SAS version 8.2 (SAS Institute Inc., Cary, NC 2001) was used for all statistical analyses and significance was set at $P<0.05$ for all comparisons.

Results and Discussion

Site index for the stand averaged 32.0m at base age 50 years using equations from Beck (1971) for white pine in the southern Appalachians. This is well above the site index noted by Doolittle (1962), who found average site index for white pine in the southern Appalachians to be 24.4m at base age 50. Dale and coworkers (1989) reported average site index of white pine in southeastern Ohio to be 23.5. The response to thinning from age 17 to age 26 is shown in Table IV.1. As expected, total height of the thinned treatment was greater than that of the unthinned treatment for both ages due to the removal of intermediate and suppressed trees from the plots treated with low thinning. Thinning increased dbh by nearly 4.5cm over the nine years since treatment compared to the unthinned treatment (27.9cm versus 23.4cm for these treatments, respectively). The annual diameter increment calculated from the repeated measures data for the thinned treatment was 0.84cm yr^{-1}, while that for the unthinned treatment was 0.58cm $yr^{-1,}$ and this difference was significant (*P*<0.0001) (Figure IV.1). Basal area was not significantly different between treatments. Gillespie and Hocker (1986), in a study of white pine thinning response in New England, found that stand basal area was not affected by thinning, but mean diameter increment was significantly greater in the thinned plots. Both treatments have accrued a large amount of basal area (15.6m^2 ha^{-1} and 12.9m^2 ha^{-1} for thinned and unthinned, respectively). Comparing the stand density prior to thinning (1438 stems ha^{-1}) with the stand density in the unthinned treatment, it can be seen that substantial mortality has taken place in the unthinned treatment, as there remains only 63% of the original number of trees in the unthinned plots. Low thinning has been shown to decrease competition-induced mortality for white pine in the southern Appalachians

(Della-Bianca, 1981). The volume per acre in the thinned treatment was not significantly different compared to the unthinned treatment. Additionally, the volume of the thinned plots is standing volume and does not account for the $94.2 m^3 ha^{-1}$ removed during the thinning. Individual tree volume was significantly different between treatments at age 26 (P = 0.0327), which is reasonable given the diameter growth response observed.

Table IV.1. Thinning effects at age 26, nine years after thinning, and projected thinning effects at age 30 for a white pine stand growing on a reclaimed surface mine in southwestern Virginia.

Treatment	DBH (cm)	Total Height (m)	Basal Area ($m^2 ha^{-1}$)	Trees per Hectare	Stand Volume ($m^3 ha^{-1}$)	Volume per Tree (m^3)	Volume in Sawtimber (%)	Value per Hectare ($)
Age 26:								
Thinned	27.9	19.3	36.3	566	289.6	0.52	62	5641
Unthinned	23.4	17.0	42.9	899	312.7	0.35	55	5481
Pr > F	0.018	0.017	0.111	0.044	0.360	0.033	0.514	0.593
Age 30:								
Thinned	33.0	22.1	49.8	566	465.6	0.84	92	11265
Unthinned	26.2	19.7	53.0	899	456.9	0.51	66	8807
Pr > F	0.007	0.018	0.415	0.044	0.796	0.015	0.015	0.008

At age 26, low thinning had not created a significant difference in the proportion of stand volume in the sawtimber size classes compared to the unthinned treatment, but with the continued increased diameter growth rates (Figure IV.1) this shift would be expected in the near future. Stand table projection was used to predict the stand parameters at age 30. This projection indicated that there would be nearly a three-inch difference in dbh between the thinned and unthinned treatments, which was statistically significant (P = 0.0066) (Table IV.1). Due to the accelerated diameter growth, stand basal area would be very similar for thinned ($49.8 m^2$) and unthinned ($53.0 m^2$) treatments.

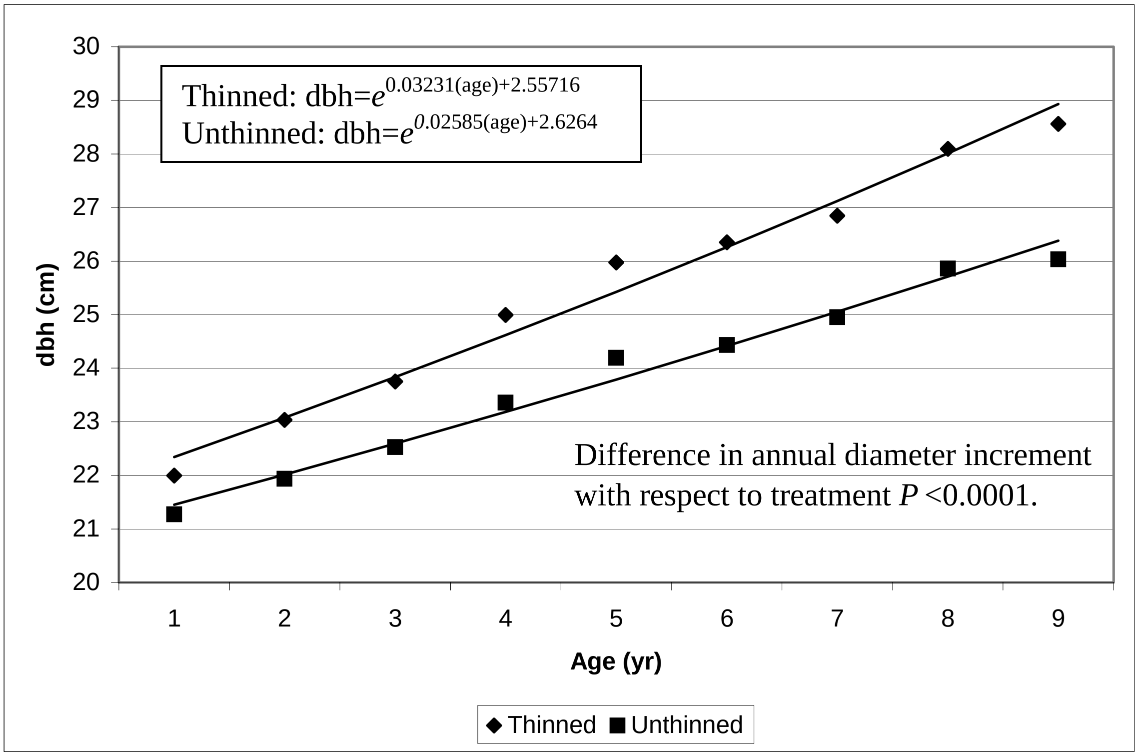

Figure IV.1. Diameter response to thinning of a 26-year-old white pine stand growing on a reclaimed surface mine site in southwestern Virginia.

At age 30, standing volume in thinned plots was estimated to be 465.6m^3ha^{-1}, which would surpass the volume of the 456.9m^3ha^{-1} in the unthinned treatment. Volume per tree was estimated to be nearly 0.34m^3 $tree^{-1}$ more in the thinned treatment than the unthinned treatment at age 30, compared to an approximate 0.17m^3 $tree^{-1}$ difference between the same treatments, respectively, at age 26. It is estimated that at current diameter growth rates, 92% of the volume in the thinned treatment would be sawtimber compared to 66% for the unthinned treatment, and this difference would be statistically significant (P = 0.0154). Results of a white pine thinning study in the southern Appalachians found that at both 80 and 100 years, thinning had shifted the diameter distributions to larger size classes, but failed to increase cumulative yield compared to an unthinned control (Della-Bianca, 1981; McNab and Ritter, 2000). McNab and Ritter

(2000) did note that site quality, as measured by site index, was higher in the unthinned control, indicating that if site qualities were equal, it might be possible for thinned plots to produce more cumulative yield. Due to higher stumpage values for sawtimber, the higher proportion of sawtimber in the thinned treatment would translate into a significantly higher value per acre for the thinned treatment (P = 0.0079), whereas at age 26, both treatments had similar standing volume and proportion of volume in sawtimber, and consequently there was no significant difference in value per acre at age 26. The magnitude of the shift into the sawtimber class for both treatments at ages 26 and 30 can be seen in Figure IV.2. The result of this shift is an approximate 200% increase in value for the thinned treatment from age 26 to age 30 (\$5641 and \$11265ha^{-1} for ages 26 and 30, respectively) and an approximate 160% increase in value for the unthinned treatment (\$5481 and \$8807ha^{-1} for ages 26 and 30, respectively).

To examine the economic feasibility of establishing stands with this level of productivity on surface mined lands, it is important to understand that several factors have been found to limit tree productivity on post-SMCRA reclaimed surface mined land. The two major limitations are soil compaction and competing vegetation (Ashby, 1991) that result from SMCRA's requirement to return the land to approximate original contour and to stabilize the reclaimed landscape from erosion. Burger and Zipper (2002) have outlined procedures for restoring forests on surface mined lands. Part of their prescription includes the establishment of a tree-compatible ground cover, which is intended to minimize the need for competition control treatments when forestry is chosen as the post-mining land use; however, these treatments may still be required if other more

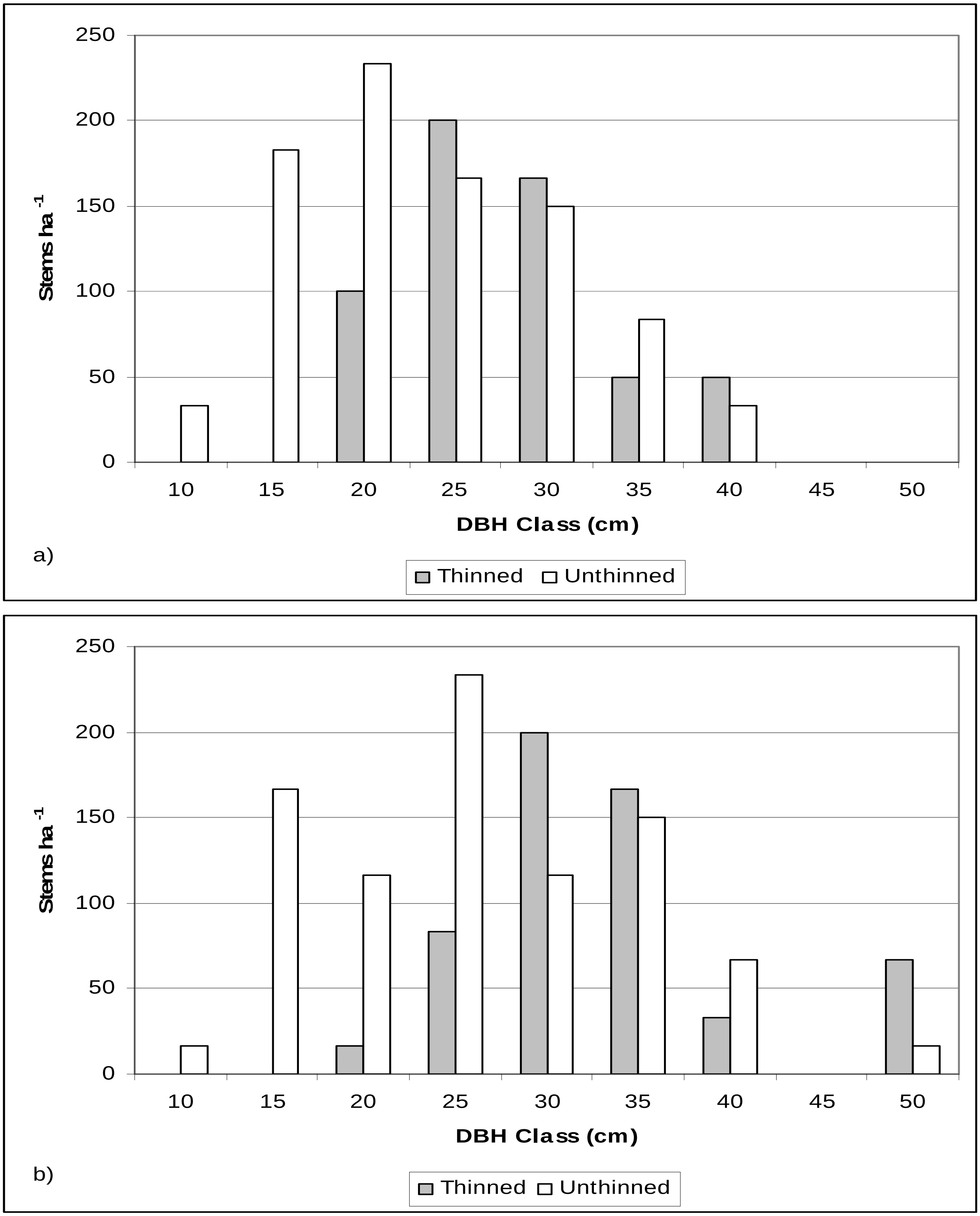

Figure IV.2. Diameter distributions for (a) stand at age 26 and (b) stand projected to age 30 for a 26-year-old white pine stand growing on a reclaimed surface mine in southwestern Virginia.

aggressive herbaceous species become established on the site. As such, using the stand value information from this study, net present values (NPV) and internal rates of return (IRR) were calculated for four different management scenarios that are likely to face landowners who wish to establish forests on post-SMCRA mined lands. The NPV allows for comparison of the different scenarios while accounting for the opportunity costs associated with each investment scenario. Important assumptions include having a tree-compatible ground cover established by the mining company, having appropriate spoil materials for tree growth (Torbert and Burger, 2000), and having these materials returned to the surface in an uncompacted state. It was also assumed that the harvested volume resulting from thinning would cover the cost of the thinning operation at no net benefit or cost (harvestable volume would have generated \$667ha^{-1} based on pulpwood prices and the cubic foot volume removed during thinning). A 6% discount rate was used in calculating NPV. The scenarios evaluated differ only with respect to costs incurred over the rotation and include:

Scenario 1. Establishment costs only of \$618ha^{-1} (Burger and Zipper, 2002)

Scenario 2. \$618ha^{-1} establishment cost and \$173ha^{-1} herbicide cost (based on author estimates) in first year

Scenario 3. \$618ha^{-1} establishment cost and \$173ha^{-1} herbicide cost in years 1 and 2

Scenario 4. \$618ha^{-1} establishment cost and \$173ha^{-1} herbicide cost in years 1, 2, and 3

Scenario 5. All establishment and herbicide costs borne by mining company up to year 5 to obtain bond release.

Cash flows for each scenario are depicted in Figures IV.3 and IV.4. The results of this simulation show that at age 26, the IRR's and NPV's are virtually the same between thinned and unthinned treatments for Scenarios 1 through 4 and ranged from approximately 9% when management inputs include only establishment costs to approximately 6.5% using the most intensive scenario (Table IV.2). Using projected values at age 30, the IRR's for Scenarios 1 through 4 differed by approximately 1% between the treatments, with the IRR of the thinned treatment being higher. For the thinned treatment, IRR's range from 10.2% to 8.1% from the least intensive to the most intensive scenarios respectively. For the unthinned treatment the range is 9.3% to 7.2% respectively. When commercial forestry is specified as the post-mining land use, mining companies are required by law to establish a minimum stocking of crop trees per hectare within a fixed time period to obtain bond release. In Virginia, 988 crop trees ha^{-1} are required (Burger and Zipper, 2002). It is important to understand that scenario 5 is not typical for forestry business enterprises and represents a situation in which all harvest revenues are purely profit to the landowner as there are no establishment costs to be considered. This resulted in NPV values that were approximately \$600 ha^{-1} greater under scenario 5 when compared to scenario 1, with this difference increasing as additional herbicide costs are incurred. Calculation of IRR for scenario 5 was not possible given that revenues were generated, but no cost were incurred, meaning that regardless of the interest rate, NPV could not be set equal to zero.

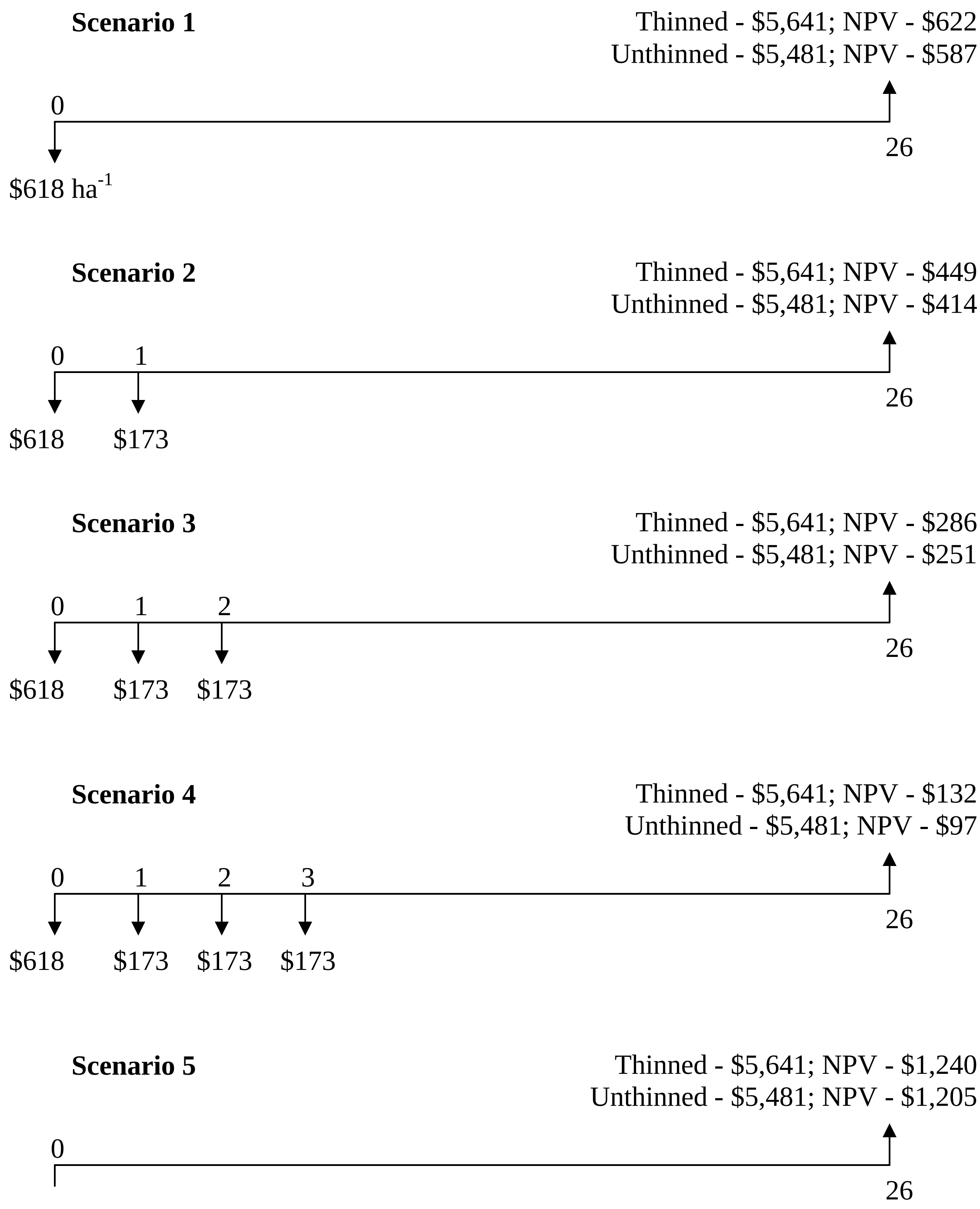

Figure IV.3. Cash flow diagrams for thinned and unthinned treatments under Scenarios 1-5 at age 26 for a white pine stand growing on a reclaimed surface mine in southwestern Virginia.

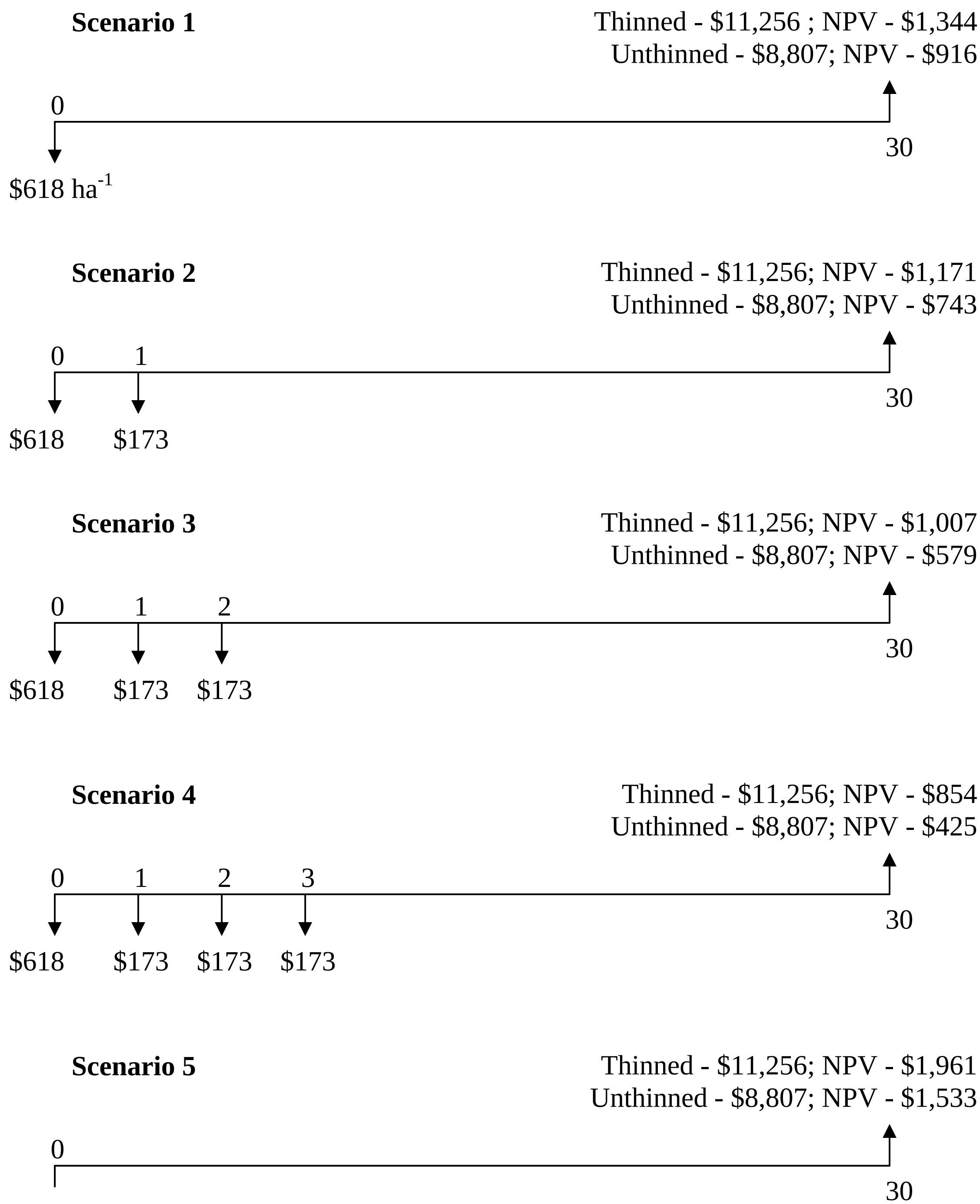

Figure IV.4. Cash flow diagrams for thinned and unthinned treatments under Scenarios 1-5 at age 30 for a white pine stand growing on a reclaimed surface mine in southwestern Virginia.

Table IV.2. Net present value ($ ha^{-1}) at 6% interest and internal rate of return by thinning treatment and stand age for a 26-year-old white pine stand growing on a reclaimed surface mine in southwestern Virginia.

Age and Treatment	Management Scenario*									
	1		2		3		4		5	
	NPV ($)	IRR (%)	NPV ($)	IRR (%)	NPV ($)	IRR (%)	NPV ($)	IRR (%)	NPV ($)	IRR (%)
Age 26:										
Thinned	622	8.9	449	7.9	286	7.1	132	6.5	1240	---
Unthinned	587	8.8	414	7.7	251	7.0	97	6.3	1205	---
Age 30:										
Thinned	1344	10.2	1171	9.3	1007	8.6	854	8.1	1961	---
Unthinned	916	9.3	743	8.4	579	7.7	425	7.2	1533	---

*Scenario 1: $618ha^{-1} establishment costs only
Scenario 2: $618ha^{-1} establishment cost and $173ha^{-1} herbicide cost in first year
Scenario 3: $618ha^{-1} establishment cost and $173ha^{-1} herbicide cost in years 1 and 2
Scenario 4: $618ha^{-1} establishment cost and $173ha^{-1} herbicide cost in years 1, 2, and 3
Scenario 5: All costs to age 5 paid by mining company

From this simulation, it can be seen that if sawtimber production is the management objective, and the desired rotation age is around 30 years, thinning near mid-rotation is a better economic decision than leaving the stand to grow in an unthinned state, especially considering that the average diameter of unthinned trees is only projected to be 26.2cm at age 30 and only 66% of the stand volume is in sawtimber.

Conclusions

The results of this investigation reveal that, at a site index of 32.3m, this stand is more productive than established averages for white pine in the southeastern United States. Additionally, volume growth rates of 11.1m^3 ha^{-1} yr^{-1} in the thinned plots compare favorably with productive stands of loblolly pine found in the southeastern U.S., thus demonstrating the potential of reclaimed surface mines to support productive forests. Thinning the stand at age 17 rapidly increased the diameter growth of the residual trees. Volumes and values for the stand were no different at age 26; however, at each treatment's respective growth rates based on a stand table projection, stand values were significantly higher for the thinned treatment by age 30 due to a shift in the diameter distribution of this treatment toward the sawtimber size classes. These trends in terms of thinning response are similar to trends found in white pine stands growing on native soils, and as such, it appears that white pine growing on reclaimed surface mines can be managed similarly to plantations on native soils. Economic analysis of stand value information revealed that stands growing at this level of productivity on reclaimed mined lands should provide landowners with favorable returns on their investment even when establishment and weed control costs are borne by the landowner. When establishment costs for stands at this level of productivity are borne by the mining companies as part of the reclamation process as required by the SMCRA, the before-tax NPV the landowner could realize is \$1,961 ha^{-1}.

CHAPTER V

RELATIONSHIP OF MINE SOIL PROPERTIES TO SITE PRODUCTIVITY OF A 27-YEAR-OLD WHITE PINE STAND ON A RECLAIMED SURFACE MINE IN SOUTHWESTERN VIRGINIA

Abstract

Several studies have determined which mine soil properties are important to the productivity of young forest stands; however, little information exists regarding what mine soil properties are important to the productive capacity of mature stands. This study related mine soil properties observed in the rooting depth of a mature white pine stand to the productivity of the stand, as rooting depth has already been established by numerous researchers as an important determinant of tree productivity on reclaimed surface mines. Rooting depth was strongly correlated with site index (r = 0.563), indicating its potential importance. Results from multiple regression analysis revealed that, in order of increasing importance, N mineralization index, bulk density, sand percentage of the fine soil fraction, and the percentage by depth of oxidized sandstone spoil in the rooting depth were important in determining site index for this stand (R^2 = 0.7174). Excessive bulk density levels and large relative increases in soluble salt levels were likely responsible for observed root restriction. Of all the spoil materials found in the soil profiles within the stand, oxidized sandstone spoils appeared to have the most favorable chemical properties for tree growth, and this is further evidenced by the inclusion of a measure of this property in the regression model for this site. Productive forests can be established on surface mined land when oxidized sandstone spoil is returned to the surface in sufficient depth.

Key Words: Bulk density, sand, nitrogen, sandstone, mine soil, rooting depth, electrical conductivity

Introduction

Eastern white pine (*Pinus strobus* L.) is one of the most extensively planted tree species on reclaimed surface mined lands in the Appalachian coalfield region. White pine is popular because of its ability to grow rapidly on soils with low fertility. Because it has been widely planted on reclaimed surface mines, there have been numerous studies of the factors related to white pine productivity on mine soils.

Torbert and coworkers (1988) developed two models to predict growth of 10-year-old white pine based on mine soil properties. The first model related four-year height growth to rooting volume index (RVI), where RVI is the depth to a restrictive layer multiplied by the percentage of soil-sized particles in the upper 10cm of soil. In this model, RVI was positively related to height growth and explained 51% of the variation in height growth. The second model predicted total height of the trees as a function of (in order of increasing importance) RVI, electrical conductivity (a measure of soluble salts), and extractable phosphorous (P). All variables were positively related to tree height, and the model explained 53% of the variation in tree height. This study points out the importance of maximizing the depth to a root-restricting layer during reclamation, as increasing the percentage of soil-sized particles may not be possible depending on the availability of spoil materials during reclamation.

Andrews and coworkers (1998) developed a model for 5- to 9-year-old white pine height growth using two-year terminal height growth as the dependent variable. Rooting depth was the most important variable, with other important variables being electrical conductivity, surface soil P, surface soil manganese (Mn), and slope. These variables accounted for 48% of the variability in height growth. Height growth was greater on steeper slopes, possibly due to the more compacted nature of level areas as shown by the negative correlation between slope percent and bulk density. The most important chemical property affecting growth was electrical conductivity (EC), followed by extractable P. Height growth in this study was found to decline when exchangeable Mn levels exceeded 20mg kg^{-1}.

Rodrigue and Burger (2004) related tree height growth as measured by site index (SI) to mine soil properties of 14 mine soils in the eastern and midwestern coalfields. In the order of significance to the regression model, the five variables most important to SI were: base saturation, coarse fragment percentage, available water holding capacity, C horizon total porosity, and EC. The model developed using these five variables explained 52% of the variation in SI. Of the three physical properties of mine soils, both available water holding capacity and C-horizon total porosity were positively related to tree productivity. Both of these properties are affected by reclamation practices; soil compaction would lead to a decrease in the value of these properties, thus causing a decrease in growth.

All of the previously mentioned investigations have concluded that rooting depth or properties such as available water holding capacity, which increase as rooting depth increases, are important variables in determining tree growth. Increases in rooting depth translate into an increase in the soil volume that can be exploited by the roots, thus giving the tree access to more soil resources. Given that rooting depth has been so well established as a limiting factor to good tree growth on reclaimed surface mined land, the purpose of this investigation was to examine the soil properties associated with horizons located in the rooting depth of a mature white pine stand and to relate the variability of these soil properties, integrated over the rooting depth, to tree growth as measured by site index. Horizons below the rooting depth were identified and examined to determine the cause of root restriction.

Methods and Materials

Field Methods

The study area was located on a surface mine in Wise County, Virginia, established prior to the Surface Mining Control and Reclamation Act of 1977. The stand age was 26 years at the time of the study (2004) and the stand had been thinned at age 17. The stand was sampled to determine the range in site index (SI) by measuring the total height of the three closest dominant and co-dominant trees located at the intersection of a 15.2m x 15.2m grid system. From this data, the SI of the stand was found to range from 22.6m to 37.5m at base age 50 years using SI equations for white pine in the southern Appalachians (Beck, 1971). Using these data, the stand was divided into different SI categories.

A series of 27 soil pits were excavated throughout the stand with pit locations occurring at points along the grid system used to estimate site index. A minimum of two soil pits were excavated in each SI category to ensure that the range in SI was covered. Soil pits were located at the base of a tree used to estimate SI and were excavated to the lesser of bedrock or 2m. Standard soil description techniques were used to describe the soil horizons in each pit (Schoeneberger et al., 2002). Loose soil samples were obtained for laboratory analysis from each horizon. A second soil sample was collected from each horizon and was placed in a plastic bag and stored on ice during transport to the lab. A 4.8cm diameter by 5cm deep soil core was collected from each horizon and used to determine the bulk density of the soil (Blake and Hartge, 1986). All pits had a thin A horizon present; however, only A horizons greater than 5cm deep were sampled. The A horizon was included in the sample of the next lowest horizon if it was less than 5cm deep. At the end of the growing season, foliage was collected from each of the three trees used to estimate SI for each pit to determine foliar nutrient levels by severing live branches from the upper third of the trees crown with a shotgun and then collecting foliage from this branch.

Laboratory Methods

Foliage samples were dried at 65°C for a minimum of 48 hours and then ground using a Wiley mill to pass a 1mm screen. Equal weights of ground foliage were composited for each of the three trees surrounding each soil pit. Total foliar carbon (C) and nitrogen (N) were determined using an Elementar varioMAX CNS analyzer (Mt. Laurel, NJ), and foliar calcium (Ca), magnesium (Mg), potassium (K), and P were determined after dry ashing and digesting with 6*N* HCl. Elemental concentrations of foliar and soil nutrients were determined using a SpectroFlame Modula Tabletop inductively coupled plasma spectrophotometer.

Soil samples were air dried and sieved through a 2mm screen to separate coarse fragments. Coarse fragments were washed to remove excess soil and weighed after drying to determine the percent by weight in each horizon. Particle size analysis was conducted on each sample using the hydrometer method (Gee and Bauder, 1986). Soil pH was measured in a 1:2 soil/water mixture (McLean, 1982). Electrical conductivity was determined in a 1:5 soil/water mixture (Rhoades, 1982). Exchangeable cations, including Ca, Mg, K, sodium (Na), aluminum (Al), and Mn, were extracted with ammonium acetate (NH_4OAc) (Thomas, 1982) and dilute hydrochloric and sulfuric acid (Mehlich I) (Olsen and Sommers, 1982). Soil P was estimated using the Mehlich I extraction as well as by extraction with sodium bicarbonate (Olsen and Sommers, 1982). Soil N was characterized using a 28-day aerobic mineralization procedure of field moist soil (Hart et al., 1994) in which N concentrations resulting from extraction with 2*M* KCl after 28 days less N concentrations of extractions made at the start of the 28-day period provided an index of net N mineralization. Ammonium and nitrate concentrations were determined using a Bran+Luebbe TRAACS 2000 Autoanalyzer II (Buffalo Grove, IL).

Data Analysis

Soil profile characteristics determined between the soil surface and the bottom of the rooting depth included: depth of A horizon, depth to a non-sandstone spoil, cumulative depth of sandstone spoil, and percentage by depth of sandstone spoil in the rooting zone. Rooting depth was the depth at which few or less, fine or very fine white pine roots occurred in the profile, and sandstone spoil, for the purposes of this study, refers to oxidized sandstone spoil material. Measures of soil physical properties were expressed as a weighted average of all horizons in the rooting depth of the tree for each soil pit as:

$$WSP_i = \sum_{j=1}^{n} (PP_i)_j \times Thickness_j / RD \qquad [1]$$

where: WSP_i = Whole soil physical property *i*

$(PP_i)_j$ = Value of physical property *i* in the j^{th} horizon in the rooting depth

$Thickness_j$ = Thickness of the j^{th} horizon in the rooting depth

RD = Total depth of rooting

Soil nutrient content (kg ha^{-1}) was calculated for the rooting depth as:

$$WSN = \sum_{i=1}^{n} NC_i \times Thickness_i \times BD_i \times CF_i \qquad [2]$$

where: WSN = Whole soil nutrient content of all horizons in rooting depth (kg ha^{-1})

NC = Nutrient concentration of the i^{th} horizon in the rooting depth (mg kg^{-1})

$Thickness_i$ = Thickness of the i^{th} horizon in the rooting depth

BD_i = Bulk Density of the i^{th} horizon in the rooting depth (g cm^{-3})

CF_i = Coarse fragment percentage by weight of the i^{th} horizon in the rooting depth

Multiple regression analysis was used to determine the soil properties, which, when integrated over the entire rooting depth, most strongly related to the SI of white pine. Scattergrams of each variable and its relationship to SI were generated to determine whether variable transformation was appropriate. A correlation matrix was generated among all variables for the purpose of screening variables for inclusion in the model. Variables were eliminated if their correlation coefficient was less than 0.10, if their correlation to another potential regressor was very strong (particle size classes, for example, which had highly significant correlations between them), or if the particular variable had a correlation, but was believed not to be of biological importance (extractable Na, for example). Subsequent to screening, candidate models were generated using Cp, Max R, and stepwise selection procedures. Variance inflation factors (VIF) were generated for the candidate models to diagnose any multicollinearity problems. Model refinement consisted of leverage and influence diagnostics including Cook's D, DFFITS, DFBETAS, and hat diagonal statistics. Standardized regression coefficients were also obtained for each regressor in the final model to determine which soil properties had the most influence on SI. SAS version 8.2 (SAS Institute Inc., Cary, NC 2001) was used for all statistical analyses.

Results and Discussion

Soil Properties Important to White Pine Productivity

Rooting depth had a strong and significant correlation with SI in this study (r = 0.563) (Table V.1), indicating the potential importance of rooting depth to the productive capacity of this stand. Depth to a root-restricting layer was found to be an important variable in other soil-site studies on reclaimed mined land (Andrews et al., 1998; Torbert et al., 1988). Increased rooting depth provides trees with increased access to water and nutrients in addition to better structural support. Although rooting depth was not included in the regression model by itself, all chemical properties used were aggregated within the rooting depth favoring deeper soils.

Of the 34 soil variables measured (Table V.1), 16 were included in the initial multiple regression (bold print in Table V.1) based on the screening statistics described above. Using these 16 regressors, all three selection procedures selected the following model as the best model to predict SI of white pine on the soils studied:

$$SI = 28.35 + 0.16(Nmin) + 5.17(BD) - 12.73arsin(\%sand) + 2.29arsin(\%SSspoil) \quad [3]$$

where: SI = Site Index (m)

Nmin = 28 Day Mineralized N (kg ha^{-1}) as calculated using Eq. 2

BD = Bulk Density (g cm^{-3}) as calculated using Eq. 1

Arsin(%sand) = Arcsine of Sand (%) as calculated using Eq. 1

Arsin(%SSspoil) = Arcsine of percentage by depth Sandstone Spoil in the Profile

Table V.1. Values of soil properties integrated over the observed rooting depth and their correlation with site index for a white pine stand growing on a reclaimed surface mine in Wise County, Virginia. Regressor variables are indicated in bold type.

Variable	Mean	Standard Deviation	Range Min	Range Max	Correlation with SI	Pr>F
Soil Profile Characteristics:						
Depth of A Horizon (cm)	**4.0**	**2.1**	**0**	**9**	**0.142**	**0.479**
Depth to non-Sandstone Spoil (cm)	**63**	**60**	**0**	**200+**	**0.209**	**0.296**
Cumulative Depth Sandstone Spoil (cm)	**92**	**65**	**13**	**200+**	**0.489**	**0.010**
Sandstone Spoil in Profile (%)	**60**	**30**	**10**	**100**	**0.110**	**0.584**
Total Spoil Depth (cm)	162	56	13	222+	0.499	0.008
Rooting Depth (cm)	**121**	**66**	**13**	**222+**	**0.563**	**0.002**
Physical Properties:						
Bulk Density (g cm^{-3})	**1.43**	**0.24**	**0.93**	**1.79**	**0.347**	**0.076**
Sand (%)	**61.9**	**13.8**	**30.1**	**87.1**	**-0.434**	**0.024**
Silt (%)	20.7	7.9	6.1	38.2	0.381	0.050
Clay (%)	**16.4**	**7.5**	**6.8**	**38.2**	**0.373**	**0.056**
Coarse Fragments (%)	**23.6**	**10.2**	**5.7**	**50.8**	**0.395**	**0.042**
Chemical Properties:						
28 Day Mineralized N (kg ha^{-1})	**14.1**	**9.7**	**-1.1**	**32.4**	**0.623**	**0.001**
Total Extractable N (kg ha^{-1})	8.7	10.1	0.1	39.7	0.499	0.008
Extractable NH_4^+(kg ha^{-1})	6.3	6.3	0.1	22.7	0.463	0.015
Extractable NO_3^- (kg ha^{-1})	2.4	4.7	0.0	20.1	0.455	0.017
28 Day Mineralized NH_4^+(kg ha^{-1})	10.3	7.6	-1.8	24.9	0.507	0.007
28 Day Mineralized NO_3^- (kg ha^{-1})	3.8	4.4	-2.3	14.4	0.491	0.009
Mehlich I P (kg ha^{-1})	**44**	**33**	**4**	**129**	**0.476**	**0.012**
NH_4OAc Mg (kg ha^{-1})	1205	979	55	3910	0.099	0.622
NH_4OAc K (kg ha^{-1})	**749**	**437**	**75**	**1751**	**0.614**	**0.001**
NH_4OAc Ca (kg ha^{-1})	**2410**	**2767**	**154**	**13239**	**-0.121**	**0.547**
NH_4OAc Na (kg ha^{-1})	210	127	22	583	0.547	0.003
Sum NH_4OAc Bases (kg ha^{-1})	4574	3821	371	18042	0.026	0.897
Exchangeable Al (kg ha^{-1})	**75**	**66**	**2**	**221**	**0.210**	**0.292**
Exchangeable Mn (kg ha^{-1})	**222**	**129**	**55**	**519**	**0.435**	**0.023**
Mehlich I K (kg ha^{-1})	517	334	57	1250	0.610	0.001
Mehlich I Ca (kg ha^{-1})	2412	2291	184	10805	-0.037	0.856
Mehlich I Mg (kg ha^{-1})	1027	802	59	3099	0.218	0.275
Mehlich I Zn (kg ha^{-1})	27	20	1	80	0.246	0.216
Mehlich I Mn (kg ha^{-1})	361	220	63	882	0.487	0.010
Mehlich I Cu (kg ha^{-1})	18	30	0	143	0.360	0.065
Mehlich I Fe (kg ha^{-1})	322	240	30	894	0.619	0.001
Electrical Conductivity (dS m^{-1})	**0.03**	**0.01**	**0.01**	**0.06**	**0.360**	**0.065**
pH	**4.6**	**0.3**	**3.8**	**5.1**	**-0.372**	**0.056**

+ Indicates that depth of this variable continued below the depth of the excavated soil pit.

This model had an R^2 of 0.72, an adjusted R^2 of 0.66, and was highly significant ($P < 0.0001$). Variance inflation factors for each variable were low (Table V.2), indicating no multicollinearity between regressors.

Table V.2. Regression statistics for independent variables used to predict white pine site index on a reclaimed surface mine in Wise County, Virginia.

Variable	Partial Test	Standardized Regression Coefficient	Model R^2	Variance Inflation Factor
Nmin	0.0033	0.4226	0.4104	1.2
BD	0.0143	0.3414	0.5570	1.2
Arsin (%sand)	0.0002	-0.6128	0.6297	1.4
Arsin (%SSspoil)	0.0185	0.3300	0.7174	1.2

The most important variable in determining site index was 28-day mineralized N (Nmin), which by itself explained 41% of the variation in site index for this site (Table V.2). Given the low N status common to mine soils (Li and Daniels, 1994), it is not surprising that increased N in the rooting depth would be related to increased tree growth. In the rooting depth, 8.7kg ha^{-1} of extractable N were available to plants and 14.1kg ha^{-1} were mineralized in the rooting depth over the 28-day mineralization period (Table V.1). Both of these measures were significantly correlated to SI ranging from $r = 0.499$ for total exchangeable N to $r = 0.623$ for 28-day mineralized N, suggesting that plant-available N is important to this stand at age 26. Both of these measures of soil N have also been found to have strong correlations ($r >= 0.87$) to several growth measures of six-month-old white pine seedlings grown in Maine forest soils (Kraske and Fernandez, 1990). Further justification for the inclusion of the Nmin variable is found in the foliar N concentrations of trees in the stand. The maximum concentration found in this stand (16.1g kg^{-1}) is below the lowest concentration reported by van den Burg (1985) for medium to good growth of white pine in young plantations (Table V.3). Additionally, foliar N concentration was found to have a significant (P = 0.017) and positive correlation with site index (r = 0.456).

Table V.3. Foliar nutrient data and comparison to published values for a white pine stand growing on a pre-SMCRA surface mine in Wise County, Virginia.

Element	Mean Concentration	Standard Deviation	Minimum	Maximum	Published Values†
N	13.6	1.4	11.2	16.1	16.7-17.1
P	1.4	0.3	1.0	2.0	1.5-1.7
K	4.4	1.1	2.8	8.6	4.5-5.1
Ca	3.5	1.0	2.2	5.6	3.3
Mg	1.2	0.2	0.8	1.9	0.7

†Values adapted from van den Burg (1985) and indicate intermediate concentration ranges for young plantations where growth is medium to good and response to fertilization is small or uncertain.

Most mine soils lack an A horizon during the early years of vegetation growth, making the N reserve in the entire rooting zone more important. Mine soils are commonly devoid of N and require fertilization with N for good growth of grasses and legumes used in reclamation (Daniels and Zipper, 1997). In terms of mine soil N and its relation to tree growth, several studies have attempted to relate total N to tree productivity (Andrews et al., 1998; Rodrigue and Burger, 2004; Torbert et al., 1988) but this variable was not significant in final regression models.

White pine has also been shown to be responsive to N fertilization in mid-rotation stands, indicating that increased availability of N should relate to increased productivity. For example, Shepard and coworkers (1991) found that 60- to 80-year-old white pine responded to all levels of N fertilization in terms of basal area growth and cubic foot volume growth on both till and outwash soils in Maine. Burgess and coworkers (1995) found that after seven years of growth, white pine stem volume was greater where fertilizer had been applied at stand establishment when weed control was implemented.

Soil bulk density (BD) had a standardized regression coefficient of 0.34137 (Table V.2), indicating that a positive relationship to SI was found. This is likely due to the increased water holding capacity that would accompany an increase in bulk density through a reduction in macropore space and a resultant increase in micropore space for a given texture (Greacen and Sands, 1980). Average bulk density was 1.43g cm^{-3} and ranged from 0.93 to 1.79g cm^{-3} in the rooting depth. The coarse textures, which were common in the rooting depth, could see increases in bulk density up to 1.75g cm^{-3} without severe root restriction as a result of increased soil strength (Kozlowski, 1999).

Standardized regression coefficients indicated that changes in sand percentage of the fine soil fraction (%sand) have the largest impact on SI and that %sand has an inverse relationship to SI (Table V.2). As the average soil texture in the stand was a sandy loam in the rooting depth, and sand percentages ranged from 30.1% to 87.1%, this relationship is likely related to the decreased water holding capacity that accompanies an increase in sand content (Brady and Weil, 2002).

Further evidence that increased water holding capacity associated with the decreased sand percentage and increased bulk density in the rooting depth could logically be related to increased SI comes from Rodrigue and Burger (2004), who found that available water holding capacity was the third most influential variable in determining the SI of mixed stands of trees on surface mined land. Coarse fragment percentage was also found to be important to tree growth by these authors, who cited decreased water holding capacity as one of the potential reasons for the inverse relationship between coarse fragment percentage and SI.

Percentage by depth of sandstone spoil in the profile (%SSspoil) had the lowest standard coefficient, but is biologically relevant and improved the R^2 by approximately 9% as a result of inclusion in the model (Table V.2). The sandstone spoils in this stand had chemical properties which were more favorable than all other spoil types for EC, all N measures with the exception of mineralized NO_3^-, and Mehlich I extractable P. For these reasons, this variable could logically be included despite the fact that inclusion of this variable would be somewhat contradictory to the %sand variable. Depth to non-sandstone spoil, cumulative depth of sandstone spoil, and sandstone spoil in the profile (Table V.1) were included as candidate regressors due to the reports of several researchers indicating that oxidized sandstone spoil is the best mine soil for pine species. Torbert and coworkers (1990) reported that pitch x loblolly pine hybrids (*Pinus rigida* P. Mill. X *Pinus taeda* L.) produced five times more stem volume when grown in oxidized sandstone spoil material than when grown in pure siltstone spoil, with volume growth increasing as the amount of sandstone present in the spoil increased. Another study found that after six months, three pine species, which were grown from seed, were significantly taller and had better survival when grown in sandstone versus siltstone spoil material (Preve et al., 1984). In addition, in a case study of white pine growth on oxidized sandstone spoil in West Virginia, Torbert and coworkers (1991) found that after five years average tree height was 2m with some trees greater than 3m tall. They reported that based on SI curves for white pine, these trees should reach heights greater than 30.5m by age 50.

Influence of Other Measured Properties

Several other mine soil properties, which were not included in the regression model, were measured in this stand if they have been found by other researchers to influence forest productivity on surface mined lands. The soil profiles were extremely variable throughout the stand (Appendix G), with successive horizons often comprised of totally different spoil materials. The different spoil materials fell into one of five main types, namely (1) coal spoil, (2) sandstone spoil, (3) coal/sandstone spoil mix, (4) dense clay material, and (5) siltstone material. Laboratory analysis revealed that these spoil types had distinctly different physical and chemical properties associated with them (Table V.4).

Examination of soil horizons immediately below the rooting depth revealed that soil density could be used to explain root restriction in several of the horizons that were observed to be root restricting. The coal spoil had the lowest bulk density (1.18 g cm^{-3}) (Table V.4), probably the result of lower particle density for coal than for mineral soil material or for coarse fragments comprised of mineral particles (1.3 versus 2.65g cm^{-3}). The sandstone, siltstone, and coal/sandstone spoils had bulk density values of 1.56, 1.44, and 1.53g cm^{-3}, respectively. The clay spoil type had the highest average bulk density at 1.72g cm^{-3}, and was found in 4 of the 27 pits. No roots were present within or below any horizons containing this spoil type. Zisa and coworkers (1980) found that root penetration of pitch pine (*Pinus rigida* P. Mill.), Austrian pine (*Pinus nigra* Arnold), and Norway spruce (*Picea abies* (L.) Karst.) after four months of growth decreased from approximately 15.0cm to approximately 2.5cm as bulk density increased from 1.2 to 1.8g cm^{-3} in both a sandy loam and silt loam soil.

Table V.4. Chemical and physical properties of spoil materials encountered in the soil profiles of a white pine stand growing on a reclaimed surface mine in Wise County, Virginia.

Soil Property	Coal		Coal/Sandstone		Clay		Siltstone		Sandstone		Sandstone A Horizon	
	Mean	(s.d.)	Mean	(s.d.)	Mean	(s.d.)	Mean	(s.d.)	Mean	(s.d.)	Mean	(s.d.)
Bulk Density (g cm^{-3})	1.18	(0.37)	1.53	(0.06)	1.72	(0.09)	1.44	(0.18)	1.56	(0.21)	1.16	(0.11)
Sand (%)	45.4	(20.9)	58.9	(4.4)	3.0	(1.9)	37.3	(15.4)	67.6	(9.5)	57.0	(13.3)
Silt (%)	29.2	(13.4)	19.2	(1.8)	47.2	(5.7)	30.2	(10.9)	19.7	(6.8)	28.5	(16.9)
Clay (%)	25.3	(14.1)	21.9	(3.0)	49.7	(6.7)	32.5	(12.2)	12.7	(3.7)	14.5	(9.1)
Soil Texture Class	Loam		Sandy Clay Loam		Clay		Clay Loam		Sandy Loam		Sandy Loam	
Coarse Fragments (%)	24.8	(14.9)	26.5	(5.4)	1.3	(1.5)	31.0	(9.7)	21.2	(12.5)	9.9	(8.9)
pH	4.47	(0.29)	4.33	(0.26)	4.38	(0.26)	4.10	(0.17)	4.74	(0.24)	4.87	(0.22)
Electrical Conductivity (dS m^{-1})	0.06	(0.04)	0.05	(0.01)	0.04	(0.02)	0.06	(0.02)	0.02	(0.00)	0.04	(0.01)
	---------- (mg kg^{-1}) ----------											
28 Day Mineralized N	0.61	(1.08)	0.18	(0.57)	0.53	(0.82)	0.92	(0.92)	2.02	(2.92)	13.15	(11.37)
Total Exchangeable N	0.44	(0.71)	0.39	(0.50)	0.48	(0.35)	0.13	(0.21)	1.08	(2.29)	10.78	(3.53)
Exchangeable NH_4^+	0.33	(0.61)	0.36	(0.49)	0.36	(0.25)	0.13	(0.21)	0.84	(1.74)	10.63	(3.64)
Exchangeable NO_3^-	0.11	(0.22)	0.03	(0.06)	0.12	(0.16)	0.00	(0.00)	0.24	(0.64)	0.15	(0.22)
28 Day Mineralized NH_4	0.31	(0.74)	0.04	(0.40)	0.21	(0.37)	0.48	(0.93)	1.66	(2.61)	12.52	(11.21)
28 Day Mineralized NO_3^-	0.31	(0.58)	0.14	(0.27)	0.31	(0.54)	0.44	(0.33)	0.37	(0.56)	0.63	(0.71)
Mehlich I P	2.1	(0.6)	2.7	(0.5)	2.0	(0.0)	2.0	(0.0)	3.8	(2.5)	4.3	(1.5)
NH_4OAc Mg	287	(241)	97	(48)	126	(36)	79	(45)	77	(54)	74	(27)
NH_4OAc K	71	(29)	67	(11)	83	(19)	79	(11)	54	(26)	69	(16)
NH_4OAc Ca	763	(675)	290	(196)	110	(108)	96	(67)	138	(131)	501	(229)
NH_4OAc Na	21	(7)	20	(7)	20	(5)	16	(4)	15	(4)	14	(5)
NH_4OAc Al	13.7	(19.0)	4.6	(5.8)	5.5	(5.2)	9.7	(6.5)	5.9	(6.8)	1.4	(1.4)
NH_4OAc Mn	13.8	(12.7)	26.9	(16.5)	0.6	(0.3)	7.8	(6.0)	22.5	(12.6)	53.6	(11.5)

Soil textures ranged from clay for the clay spoil to sandy loam for the sandstone spoil (Table V.4). Considering that the clay spoil had a bulk density of 1.72g cm^{-3} and a clay texture, it is evident why this material was always root-limiting. In the study conducted by Zisa and coworkers (1980), root penetration in the finer textured silt loam soil was reduced to less than 5cm at a bulk density of 1.4g cm^{-3} whereas root penetration was virtually unaffected in the sandy loam soil, indicating that finer-textured soils become root-limiting at lower BD than coarser-textured soils.

Further examination of root-restricting horizons (those immediately below the rooting depth) indicated that when root restriction was not attributable to bulk density, there was a large increase in EC compared to the horizon immediately above. As all clay spoils were limiting in respect to soil density and no sandstone spoils were found to be root-limiting, the EC of the coal, coal/sandstone, and siltstone spoils were examined. Average EC values for these spoils (range of 0.05-0.06dS m^{-1}) were nearly double those found in sandstone spoils (0.03 dS m^{-1}), with extreme values occurring occasionally as indicated by the high standard deviations associated with these values (Table V.4). Soluble salt levels (as measured by EC) have been found to adversely affect white pine productivity in numerous studies (Andrews et al., 1998; Rodrigue and Burger, 2004; Torbert et al., 1988). In addition, McFee and coworkers (1981) found EC to be negatively related to plant growth. The EC values found in this study are well below those reported by Torbert and coworkers (1988) and by Andrews and coworkers (1998) as adversely affecting tree growth, but similar to levels found by Rodrigue and Burger (2004), who suggested that trees may be more sensitive to salts than has been previously thought.

Mine soils have been shown to develop discernible A horizons in as little as four years (Haering et al., 2004) and we found A horizons ranging from 0cm to 9cm with an average depth of 4cm in the stand. The correlation between A horizon thickness and SI was not significant, although the A horizons were much higher in N and P than the spoil materials (Table V.4). These results indicate that, although thin, A horizons may make an important contribution to the soil nutrient supplying capacity for N and P. Thickness of the A horizon of a soil has been found to be positively related to loblolly pine productivity in the southeastern U.S. (Coile, 1952; Campbell, 1978). This is not surprising, given that A horizons are high in organic matter, which supplies large amounts of N, P, and other nutrients, and also have favorable soil structure and water holding characteristics.

Mean soil pH was found to be 4.6 for the site with little variation between spoil types (4.1 in siltstone to 4.7 in sandstone spoils respectively). The correlation between pH and site index was $r = -0.372$, but was not significant. An inverse correlation between pH and SI would fit well with the relationship observed by Torbert and co-workers (1990), who found that as soil pH increased from 5.0 to 7.0, volume of pitch X loblolly hybrids (*Pinus rigida* P. Mill. X *Pinus taeda* L.) decreased. In our study, the siltstone spoil had the lowest pH and the sandstone spoil the highest, which is contrary to pH trends reported by Torbert and co-workers (1990) for the same materials, respectively; however, soil pH was found to decrease over the course of five years in the siltstone spoils. At the end of this five-year period, however, pH of the siltstone spoils were still much higher than those in the sandstone spoils (Haering et al., 1993).

The $NaHCO_3$ extractable P was generally below the detection limit of the analytical equipment (<0.0154mg kg^{-1}). Several investigations of tree productivity on mine soils have found $NaHCO_3$ extractable P to be an important variable in predicting tree productivity (Andrews et al., 1998; Torbert et al., 1988). For this reason, Mehlich I extractable P was measured to provide a relative estimate of P availability, though this procedure may overestimate plant available P in mine soils (Daniels and Amos, 1982). The Mehlich I extractable P level in the rooting depth averaged 44kg ha^{-1}, ranging from 4 to 129kg ha^{-1}, and had a significant correlation with SI of $r = 0.476$, indicating the potential importance of P in determining site index (Table V.1). Average Mehlich I extractable P concentration of all horizons was 3.1mg kg^{-1}, which is close to the concentration of 3.0mg kg^{-1} at which P fertilization is recommended in southern pine plantations (Fisher and Binkley, 2000). The sandstone spoil had nearly twice the P concentration (3.8mg kg^{-1}) as the coal, clay, and siltstone spoils, which had P concentrations of 2.1, 2.0, and 2.0mg kg^{-1}, respectively (Table V.4). This low level of P availability is not surprising, as mine soils in this area have been found to be inherently low in available P due to pH, carbonate content, and high P-fixing capacity of the spoil materials (Howard et al., 1988). The mycorrhizal associations observed on the root systems of the trees in this study may help this stand to maintain good growth despite low soil P levels by increasing the availability of P to the roots. The mycorrhizal associations benefit the pines by increasing the volume of soil exploited by the roots, decreasing the diffusion zone between the nutrients and the mycorrhizae, modifying the rhizosphere to make the different forms of P more easily solubilized, and through storage of large amounts of P compared to that which can be stored in the roots (Bolan, 1991).

Average NH_4Oac extractable Mn concentration for all horizons was 20.02 mg kg^{-1} (Table V.1). This Mn value fits well with the average of 15.9 mg kg^{-1} found by Andrews and coworkers (1998), who found Mn concentrations to be negatively related to white pine productivity when levels exceed 20mg kg^{-1} The highest Mn concentration was found in the coal/sandstone spoil at 26.9mg kg^{-1} with the clay spoils having the lowest concentrations (0.6mg kg^{-1}) (Table V.4). In this study, Mn had a significant and positive correlation with SI, and elevated concentrations of Mn were not associated with any potentially root-restricting horizons.

The average concentrations of Ca, Mg, and K found in all soil horizons (327, 136, and 63mg kg^{-1} respectively) are very close to values found in similar studies of mine soil properties (Andrews et al., 1998; Torbert et al., 1988). Values of 2410, 749, and 1205kg ha^{-1} of Ca, K, and Mg, respectively, were found in the rooting zone (Table V.1). A strong and significant correlation was found between K and SI (r = 0.614) and K was the only base cation that was correlated with SI. Both Ca and Mg were most concentrated in the coal spoil (763 and 287mg kg^{-1} respectively) with K being most concentrated in the clay spoil (83mg kg^{-1}) (Table V.4). Base cations are not likely to limit plant productivity on reclaimed mined lands, as mine soils commonly have very high base saturation levels (Daniels and Amos, 1982; Bussler et al., 1984) indicating favorable base cation nutrition.

Conclusions

The white pine stand studied was a productive forest. Average SI was 31.4m and ranged from 22.6m to37.5m because it was established on reclaimed surface mines with appropriate spoil materials placed in the potential rooting zone of the trees, and the rooting zone had sufficient depth. The most influential variables in determining SI based on soil properties in the rooting depth for this site were found to be 28-day mineralized N, bulk density, sand percent in the fine soil fraction, and percentage by depth of oxidized sandstone spoil in the profile. These variables explained nearly 72% of the variation in SI for white pine on this site. The inclusion of a variable indicating soil N status, strong correlations between all variables related to soil N supply with site index, in addition to low foliar N levels compared to published values for white pine, would indicate that fertilization with N near mid-rotation may increase the productivity of this mature stand and this hypothesis merits further investigation.

The rooting depth of the soil supporting this productive white pine stand had favorable physical and chemical properties, though soil N and P were found to be at low levels. Of the spoil materials encountered in the stand, it is apparent based on this study that the oxidized sandstone spoil was superior to the other spoil types (coal, coal/ sandstone mixture, siltstone, and clay) with respect to all measured soil physical and chemical properties with the exception of base cation supply capacity, which, based on regression analysis, was not found to be important in determining SI for white pine on this site.

CHAPTER VI. GENERAL CONCLUSIONS

Responses to silvicultural treatments were found in both the pre- and post-SMCRA settings. Thinning of a mature pre-SMCRA white pine stand has shifted the diameter distribution of the stand into larger diameter classes compared to unthinned controls. At age 26, nine years after thinning, the diameter growth response to thinning was statistically significant. Projecting current growth rates to age 30, it was found that the thinning treatment would have increased stand value by nearly $\$2500 ha^{-1}$ compared to unthinned plots. Volume growth rates of $11.1 m^3 ha^{-1} yr^{-1}$ in the thinned plots compare favorably with productive stands of loblolly pine found in the southeastern U.S., thus demonstrating the potential of reclaimed surface mines to support productive forests. Furthermore, the thinning response observed was comparable to responses observed on natural soils, indicating that management of white pine on surface mined lands should be similar to that commonly practiced in stands growing on natural soils.

The soil properties within the rooting depth of the trees that were found to be important in determining the productive capacity of this stand were nitrogen mineralization index, soil bulk density, sand percentage of the fine soil fraction, and percentage of oxidized sandstone spoil in the profile. Root-restricting layers were found to have either high soil density or increased concentrations of soluble salts, as measured by electrical conductivity. Reclamation of surface mined lands where forestry is the post-mining land use can use this information to ensure spoil materials are returned to the surface that have the capability of supporting productive forests. Ideally, this would be an oxidized sandstone material with no severely compacted layers or layers of overburden with high concentrations of soluble salts within 2m of the soil surface.

Additionally, the importance of the soil N variable in the model may indicate that there is potential to further increase productivity through a mid-rotation fertilization of the stand, and this is a hypothesis that warrants further investigation.

In the case of forest establishment in the post-SMCRA setting, silvicultural treatments had both positive and negative impacts associated with them. Weed control in combination with tillage produced the best combination of good survival while still providing a growth response. While hardwood survival was the best of all species at all sites, the lack of growth response could be detrimental to selecting hardwoods for this purpose as, unless weed control is continued, there is potential for the stand to succumb to competing vegetation. As was concluded in the pre-SMCRA study, oxidized sandstone spoils, such as those found at the Wise County, Virginia, site, were found to have better tree establishment and growth in comparison to the shale- and siltstone-derived soils studied in this experiment. Hybrid poplar growing on this sandstone spoil appears to have the best potential to revert lands reclaimed to grasses back to forests, as these trees, at heights greater than 1m after one year, should ensure that a fully stocked stand develops without further weed control. That is not to say, however, that continued weed control would not benefit the productivity of the stand.

Reclamation with trees is a logical choice for the Appalachian coal-producing region, as the vast majority of these lands were forested prior to mining and the environmental benefits associated with trees are many. In terms of reclamation with trees, a pro-active approach cannot be stressed enough. It has been shown in this study and in many others that numerous pre-SMCRA surface mines that were reclaimed to forests are currently very productive. Additionally, this study, as well as many other studies, has investigated what the important properties of mine soils are in terms of growing productive forests, thus providing a substantial knowledge base for reclamation managers to use. This is information is of great value due to the number and degree and interactions found in this study and others among site conditions, silvicultural treatments, and tree species. Though not specifically addressed in this investigation, the cost of the silvicultural treatments used in establishing forests in a reactive manner cannot be overlooked, especially considering that weed control may not be needed at all if tree-compatible ground covers are sown instead of aggressive grasses and legumes, nor would tillage be necessary if the spoils were loosely dumped at the final reclaimed surface.

In conclusion, it has been shown that reclaimed surface mines can grow productive forests if the appropriate spoil materials are returned to the surface in sufficient depth. It has also been shown that surface mined lands reclaimed to pasture can be successfully reforested using silvicultural treatments to ameliorate unfavorable conditions for tree establishment and growth, though the success of these treatments was variable based on the soil characteristics of each site.

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APPENDIX A:

TOTAL DIAMETER AND TOTAL VOLUME RESULTS ASSOCIATED WITH CHAPTER III

Total diameter and total volume results for three species groups planted on post-SMCRA reclaimed surface mined lands in Lawrence County, Ohio, Nicholas County, West Virginia, and Wise County, Virginia, as affected by silvicultural treatments, are presented here. The addition of these results to the main text neither added to nor detracted from the major interpretations of the paper and were removed for brevity.

Total Diameter

There were no significant differences between species or treatments for total diameter at the installation in OH (Table A1). Total diameter ranged from 4.7mm in WC to 5.6mm in WC+T+F and from 4.3mm for white pine to 4.9mm for hardwood to 5.7mm for hybrid poplar (Table A2).

At the site in West Virginia, there was a significant interaction between species groups and silvicultural treatment (Table A1). Both white pine (4.5mm) and hardwood (5.2mm) had greater diameter than hybrid poplar (3.1mm) in WC. However, in the WC+T treatment, diameter of hybrid poplar (7.0mm) was greater than the total diameter of white pine (5.1mm). In the WC+T+F treatment, there were no significant differences among species diameters, which ranged from 4.3mm for white pine to 5.7mm for hardwood to 7.5mm for hybrid poplar.

Table A1. Analysis of variance results for survival and growth parameters for research sites in Lawrence County, Ohio, Nicholas County, West Virginia, and Wise County, Virginia.

Site and Source	Degrees of Freedom	Variable (Pr>F) Total Diameter	Total Volume
All Sites:			
Block	2	0.1650	0.0270
Site	2	0.0001	0.0001
Treatment	2	<0.0001	<0.0001
Site*Treatment	4	0.0031	0.0143
Species	2	<0.0001	<0.0001
Site*Species	4	0.0049	0.0179
Treatment*Species	4	<0.0001	<0.0001
Site*Treatment*Species	8	0.0678	0.3442
Model	28	<0.0001	<0.0001
Error	51		
Total	79		
Ohio:			
Block	2	0.0572	0.0135
Treatment	2	0.4682	0.8954
Species	2	0.2038	0.0351
Treatment*Species	4	0.2343	0.5287
Model	10	0.1182	0.0556
Error	15		
Total	25		
West Virginia:			
Block	2	0.0919	0.1134
Treatment	2	0.0003	<0.0001
Species	2	0.0099	<0.0001
Treatment*Species	4	0.0004	<0.0001
Model	10	0.0001	<0.0001
Error	16		
Total	26		
Virginia:			
Block	2	0.7203	0.9211
Treatment	2	<0.0001	<0.0001
Species	2	<0.0001	<0.0001
Treatment*Species	4	<0.0001	<0.0001
Model	10	<0.0001	<0.0001
Error	16		
Total	26		

Table A2. Total tree diameter (mm) for three species groups planted on post-SMCRA reclaimed surface mined lands in Lawrence County, Ohio, Nicholas County, West Virginia, and Wise County, Virginia, as affected by silvicultural treatments.

Site and Treatment	Species Group			Treatment Mean
	HW	HP	WP	
Ohio:				
WC	5.3	4.1	4.6	4.7 x**
WC+T	4.5	5.5	4.3	4.8 x
WC+T+F	4.9	7.4	3.8	5.6 x
Species Mean	4.9 A*	5.7 A	4.3 A	5.0
West Virginia:				
WC	5.2 A x	3.1 B x	4.5 A x	4.3
WC+T	5.6 AB x	7.0 A x	5.1 B x	5.9
WC+T+F	5.7 A x	7.5 A x	4.3 A x	5.8
Species Mean	5.5	5.9	4.7	5.3
Virginia:				
WC	4.9 A x	4.9 A x	5.0 A x	4.9
WC+T	5.6 AB x	7.0 A x	4.9 B x	5.8
WC+T+F	6.5 A x	13.9 B y	4.8 A x	8.4
Species Mean	5.7	8.6	4.9	6.4

*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 $P<0.05$.

The results for total diameter in Virginia were similar to those in West Virginia (Table A2). There were no significant differences in diameter among the species groups in the WC treatment, where diameter was 4.9mm for hardwood and hybrid poplar to 5.0mm for white pine. Diameter increased due to silvicultural treatment for hybrid poplar increasing from 4.9mm in the WC treatment to 13.9mm in WC+T+F. In the WC+T+F treatment, hybrid poplar had a significantly greater diameter than either hardwood (6.5mm) or white pine (4.8mm).

Total Volume

For total volume, there were no significant differences between species groups or silvicultural treatments in Ohio (Table A1). Total volume ranged from 10.3 cm^3 for the WC treatment to 26.9 cm^3 for the WC+T+F treatment (Table A3). Total volumes of hybrid poplar, white pine, and hardwood were 30.7cm^3, 5.2 cm^3, and 12.0 cm^3 for these species, respectively.

Table A3. Total tree volume (cm^3) for three species groups planted on post-SMCRA reclaimed surface mined lands in Lawrence County, Ohio, Nicholas County, West Virginia, and Wise County, Virginia, as affected by silvicultural treatments.

Site and Treatment	Species Group			Treatment Mean
	HW	HP	WP	
Ohio:				
WC	13.9	11.3	5.6	10.3 x**
WC+T	7.4	26.2	5.6	13.1 x
WC+T+F	14.7	54.5	3.9	26.9 x
Species Mean	12.0 A*	30.7 A	5.2 A	16.4
West Virginia:				
WC	11.7 A x	2.8 B x	6.2 C x	6.9
WC+T	17.6 A x	43.3 B y	9.0 A x	23.3
WC+T+F	16.4 A x	51.7 A y	5.2 B x	24.4
Species Mean	15.2	32.6	6.8	18.2
Virginia:				
WC	11.4 A x	15.6 A x	6.9 A x	11.3
WC+T	17.6 A xy	54.1 B x	7.0 A x	26.3
WC+T+F	25.9 A y	312.1 B y	6.2 C x	114.7
Species Mean	18.3	127.3	6.7	50.8

* 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 $P<0.05$.

There was significant interaction among species groups and silvicultural treatments at the site in West Virginia. Total seedling volume in hybrid poplar (2.8cm^3) was less than in white pine (6.2cm^3), which was less than in hardwood (11.7cm^3). However, for hybrid poplar, total volume increased as silvicultural treatment intensity increased from WC to WC+T to WC+T+F while there was no change for in total volume of either hardwood or white pine. Consequently, total volume in hybrid poplar (43.3cm^3) was greater than total volume in the hardwood (17.6cm^3) or white pine (9.0cm^3) in the WC+T treatment.

At the site in Virginia, there was also a significant interaction between silvicultural treatment and species groups. There were no differences in total tree volume among the three species groups in the WC treatment. In this treatment, total volume ranged from 6.9cm^3 for white pine to 11.4cm^3 for hardwood to 15.6cm^3 for hybrid poplar. In Virginia, total volume of both hardwood and hybrid poplar increased as silvicultural intensity increased. For hardwood, total volume increased from 11.4cm^3 in the WC treatment to 25.9cm^3 in the WC+T+F treatment. In hybrid poplar, total volume increased from 15.6cm^3 to 312.1cm^3 in the WC+T+F treatment. There was no change in total volume of white pine due to treatment. In the WC+T+F treatment, total volume was significantly different in all three species groups ranging from 6.2cm^3 in white pine to 25.9cm^3 in hardwood to 312.1cm^3 for hybrid poplar.

APPENDIX B:

HARDWOOD SUBGROUP SURVIVAL AND GROWTH ANALYSIS ASSOCIATED WITH CHAPTER III

To further differentiate among the hardwood species used, this species group was divided into three subgroups for subsequent analysis. The results for the three subgroups of hardwoods planted on post-SMCRA reclaimed surface mined lands in Lawrence County, Ohio, Nicholas County, West Virginia, and Wise County, Virginia, as affected by silvicultural treatmentsm are presented here. The addition of these results to the main text neither added to nor detracted from the major interpretations of the paper and were removed for brevity.

The HW1 subgroup consisted of red oak, sugar maple, and yellow poplar, which were common to all three sites. The shrub subgroup consisted of the nurse tree species and included Washington hawthorn, redbud, and flowering dogwood, and these species were also common to all three sites. The HW2 subgroup consisted of the commercial hardwood species that were not common to all three sites. These species are listed in Table 1 of Chapter III.

Survival

For hardwood survival percentage, site, treatment, species group, and the site by treatment interaction terms were significant in the model (Table B1). Survival was significantly less in WC+T+F in Ohio at 16% compared to WC and WC+T, which had survival percentages of 60% and 71% respectively (Table B2). In West Virginia, WC+T+F also decreased survival significantly (63%) compared to WC+T (94%). There were no differences in survival between treatments in Virginia. The survival of the site-specific hardwood species (HW2) was significantly higher than either the HW1 group consisting of red oak, sugar maple, and tulip poplar, or the shrub group (Table B2) at all three locations. Survival of the site-specific hardwoods was 10% to 13% greater than that of common hardwoods at all sites.

Table B1. Analysis of variance results for survival and growth parameters for hardwood groups at research sites in Lawrence County, Ohio, Nicholas County, West Virginia, and Wise County, Virginia.

Source	Degrees of Freedom	Variable (Pr>F)		
		Survival	Height Growth	Total Height
Block	2	<0.0001	0.0045	0.0682
Site	2	<0.0001	<0.0001	0.0001
Treatment	2	<0.0001	<0.0001	0.2632
Site*Treatment	4	0.0105	0.0429	0.1458
Species	2	0.0005	<0.0001	<0.0001
Site*Species	4	0.9222	0.0087	0.1914
Treatment*Species	4	0.8364	0.1485	0.1996
Site*Treatment*Species	7	0.5439	0.3193	0.9807
Model	27(28)	<0.0001	<0.0001	0.0003
Error*	50(51)			
Total*	77(79)			

*Degrees of freedom in parentheses are for survival only. Zero survival for shrubs in three study blocks caused the loss of one degree of freedom from all growth variables.

Table B2. Survival percentage of hardwood species groups planted on post-SMCRA reclaimed surface mined lands in Lawrence County, Ohio, Nicholas County, West Virginia, and Wise County, Virginia, as affected by silvicultural treatments.

Site and Treatment	Species Group			Treatment Mean
	HW1	HW2	Shrub	
Ohio:				
WC	66	67	49	60 x**
WC+T	64	82	65	71 x
WC+T+F	15	27	0	16 y
Species Mean	48 A*	59 B	43 A	50
West Virginia:				
WC	71	87	81	80 xy
WC+T	92	96	93	94 x
WC+T+F	68	86	35	63 y
Species Mean	77 A	90 B	69 A	79
Virginia:				
WC	82	92	69	81 x
WC+T	86	96	89	90 x
WC+T+F	79	89	79	82 x
Species Mean	82 A	92 B	79 A	85

*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 $P<0.05$.

Total Height

Site and species were the only significant terms in the model for total height (Table B1). There were no treatment effects for any site or species (Table B3). Examining species differences in total height across sites and treatments revealed that HW2 species were significantly shorter than HW1 or shrub species. Lack of interaction in this analysis facilitated that comparison of site main effects where West Virginia and Virginia were found to have significantly greater total heights than Ohio (Table B3).

Table B3. Total tree height (cm) of hardwood species groups planted on post-SMCRA reclaimed surface mined lands in Lawrence County, Ohio, Nicholas County, West Virginia, and Wise County, Virginia, as affected by silvicultural treatments.

Site and Treatment	Species Group HW1	HW2	Shrub	Treatment Mean
Ohio:				
WC	39.1	24.3	28.8	30.7 x**
WC+T	27.1	20.8	31.0	26.3 x
WC+T+F	42.2	25.3	---	33.7 x
Species Mean	36.1 A*	23.5 B	29.9 A	29.8 m†
West Virginia:				
WC	34.2	30.3	32.6	32.4 x
WC+T	40.2	32.3	45.1	39.2 x
WC+T+F	38.7	34.7	34.9	36.1 x
Species Mean	37.7 A	32.4 B	37.5 A	35.9 n
Virginia:				
WC	38.5	27.9	36.4	34.3 x
WC+T	37.5	27.2	52.8	39.2 x
WC+T+F	45.7	33.0	53.2	44.0 x
Species Mean	40.5 A	29.4 B	47.5 A	39.1 n

*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.

†m,n – For overall site means, values with the same letter are not significantly different at P<0.05.

Height Growth

There were no treatment effects in Ohio across species groups and height growth in all treatment means was negative (Table B4). In Ohio, the height growth of -6.3cm was significantly less than the mean height growth for shrubs of 1.5cm. In West Virginia, both WC+T and WC+T+F were significantly higher than WC (3.6cm and 7.4cm versus –1.2cm respectively). Height growth of HW1 species was significantly less than both

HW2 and shrub groups in West Virginia, and this mean value was negative (-1.1cm) whereas the other two groups had positive mean height growth values (6.9 and 4.1cm respectively). In Virginia, WC+T+F had a mean height growth of 9.8cm, which was significantly higher than the 4.0cm resulting from WC and the 4.4cm resulting from WC+T. HW1 species in Virginia were no different from HW2 species, which both had positive mean height growth at this site. Both of these groups had significantly less height growth than the shrub group in VA (Table B4).

Table B4. Height growth (cm) of hardwood species groups planted on post-SMCRA reclaimed surface mined lands in Lawrence County, Ohio, Nicholas County, West Virginia, and Wise County, Virginia, as affected by silvicultural treatments.

Site and Treatment	Species Group			Treatment Mean
	HW1	HW2	Shrub	
Ohio:				
WC	-1.9	-1.0	0.5	-0.8 x**
WC+T	-13.5	-3.2	2.5	-4.7 x
WC+T+F	-3.6	-2.1	---	-2.9 x
Species Mean	-6.3 A*	-2.1 AB	1.5 B	-2.8
West Virginia:				
WC	-5.9	3.0	-0.8	-1.2 x
WC+T	0.0	6.9	4.0	3.6 y
WC+T+F	2.5	10.8	9.1	7.4 y
Species Mean	-1.1 A	6.9 B	4.1 B	3.3
Virginia:				
WC	1.5	2.7	7.9	4.0 x
WC+T	0.2	3.8	9.2	4.4 x
WC+T+F	2.3	7.4	19.7	9.8 y
Species Mean	1.3 A	4.6 A	12.2 B	6.1

*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.

APPENDIX C:

PLOT LEVEL DATA FOR THE THREE SPECIES ASSEMBLAGES ASSOCIATED WITH CHAPTER III

Column Heading	Description
Site	O=Ohio, W=West Virginia, V=Virginia
Block	Block # at each site as indicated on site maps
Plot	Plot # at each site as indicated on site maps
Species	H=Hardwood, W=White Pine, P=Hybrid Poplar
Trt	Treatments: 1=weed control only, 2=weed control plus tillage, 3=weed control plus tillage plus fertilization
Hti	Initial height measured at beginning of growing season (end of May, 2004)
Htf	Final height measured late August, 2004
Diami	Initial diameter
Diamf	Final diameter
Vi	Initial Volume (Diameter squared times height)
Vf	Final Volume
Vgrow	Volume Growth (Final Vol.-Initial Vol.)
Dgrow	Diameter Growth
Hgrow	Height Growth
Avgsurv	Average Survival Percentage
n	Number of observations
	No observations for growth due to zero survival

site	block	trt	species	n (survival)	avgsurv	n (growth)	hti	htf	vf	vi	diami	diamf	vgrow	dgrow	hgrow
O	1	1	H	45	0.644	29	29.5	28.7	11.2	7.1	3.8	4.7	4.1	0.9	-0.8
O	1	1	P	54	0.444	24	0.0	40.2	14.6	0.0	0.0	4.3	14.6	4.3	40.2
O	1	1	W	45	0.578	26	15.6	20.5	4.8	2.8	4.0	4.6	2.0	0.6	4.9
O	1	2	H	51	0.941	48	31.4	31.4	11.3	6.5	4.0	5.0	4.8	1.0	-0.1
O	1	2	P	48	0.583	28	0.0	73.8	49.3	0.0	0.0	7.2	49.3	7.2	73.8
O	1	2	W	49	0.367	18	15.6	22.3	5.6	4.0	4.2	4.3	1.6	0.1	6.7
O	1	3	H	47	0.319	15	28.0	28.9	7.5	6.9	4.3	4.5	0.6	0.1	0.9
O	1	3	P	46	0.304	14	0.0	80.6	114.1	0.0	0.0	11.3	114.1	11.3	80.6
O	1	3	W	49	0.000	0	.	.	.	.	.	.	.	.	.
O	2	1	H	51	0.745	38	38.8	39.9	24.1	16.5	5.2	6.5	7.5	1.2	1.1
O	2	1	P	49	0.347	17	0.0	44.8	16.8	0.0	0.0	5.1	16.8	5.1	44.8
O	2	1	W	50	0.540	27	17.3	23.1	7.5	3.1	3.6	4.9	4.4	1.4	5.7
O	2	2	H	51	0.431	22	26.2	21.4	4.9	4.5	3.4	4.1	0.4	0.7	-4.8
O	2	2	P	45	0.511	23	0.0	45.2	18.5	0.0	0.0	5.3	18.5	5.3	45.2
O	2	2	W	50	0.180	9	22.3	26.4	6.2	4.4	4.0	4.5	1.8	0.6	4.1
O	2	3	H	54	0.037	2	53.0	54.0	32.7	31.6	6.1	6.3	1.1	0.2	1.0
O	2	3	P	45	0.178	8	0.0	52.9	47.4	0.0	0.0	7.8	47.4	7.8	52.9
O	2	3	W	49	0.143	7	14.9	20.3	4.6	2.2	3.4	4.2	2.4	0.8	5.4
O	3	1	H	46	0.413	19	27.0	23.9	6.6	6.0	4.1	4.6	0.6	0.6	-3.1
O	3	1	P	50	0.680	34	0.0	22.3	2.7	0.0	0.0	3.1	2.7	3.1	22.3
O	3	1	W	43	0.233	10	18.6	23.6	4.6	2.5	3.5	4.3	2.2	0.8	5.0
O	3	2	H	53	0.792	42	28.5	22.3	5.9	5.2	3.7	4.5	0.7	0.7	-6.2
O	3	2	P	37	0.243	9	0.0	32.1	10.8	0.0	0.0	4.0	10.8	4.0	32.1
O	3	2	W	50	0.320	16	19.9	25.4	5.1	2.9	3.5	4.2	2.2	0.7	5.5
O	3	3	H	46	0.196	9	28.9	20.2	3.8	4.8	3.7	4.1	-1.0	0.4	-8.7
O	3	3	P	54	0.019	1	0.0	19.0	1.9	0.0	0.0	3.2	1.9	3.2	19.0
O	3	3	W	59	0.051	3	14.7	25.0	3.1	1.2	2.9	3.5	1.9	0.6	10.3
V	1	1	H	50	0.960	48	28.0	31.2	9.6	6.6	3.9	4.9	3.1	0.9	3.2
V	1	1	P	50	0.720	36	0.0	46.6	20.4	0.0	0.0	5.2	20.4	5.2	46.6
V	1	1	W	53	0.642	34	16.4	22.7	6.6	4.0	4.7	5.0	2.7	0.3	6.4
V	1	2	H	49	0.980	48	31.0	35.5	14.1	7.6	4.1	5.4	6.5	1.3	4.5
V	1	2	P	56	0.804	45	0.0	63.5	46.8	0.0	0.0	6.7	46.8	6.7	63.5
V	1	2	W	54	0.852	46	17.3	23.9	7.3	3.9	4.3	5.1	3.4	0.8	6.7
V	1	3	H	44	0.977	43	35.4	44.8	31.9	9.9	4.7	7.5	22.0	2.9	9.4
V	1	3	P	58	0.569	33	0.0	112.8	228.6	0.0	0.0	11.5	228.6	11.5	112.8
V	1	3	W	54	0.463	25	14.3	19.6	5.3	2.6	4.1	4.7	2.7	0.7	5.3

site	block	trt	species	n (survival)	avgsurv	n (growth)	hti	htf	vf	vi	diami	diamf	vgrow	dgrow	hgrow
V	2	1	H	58	0.603	35	28.6	33.1	11.0	6.6	4.1	4.9	4.4	0.7	4.5
V	2	1	P	50	0.740	37	0.0	45.9	18.0	0.0	0.0	5.1	18.0	5.1	45.9
V	2	1	W	40	0.325	13	17.2	24.9	7.7	4.3	4.7	5.3	3.4	0.6	7.7
V	2	2	H	53	0.755	40	30.8	35.5	19.8	7.5	4.0	5.8	12.3	1.8	4.7
V	2	2	P	64	0.672	43	0.0	73.6	85.7	0.0	0.0	8.0	85.7	8.0	73.6
V	2	2	W	45	0.600	27	20.1	25.3	6.2	4.1	4.1	4.6	2.1	0.5	5.1
V	2	3	H	51	0.627	32	30.7	38.8	21.0	7.7	4.2	5.9	13.4	1.7	8.1
V	2	3	P	56	0.804	45	0.0	125.5	260.7	0.0	0.0	13.5	260.7	13.5	125.5
V	2	3	W	54	0.389	21	17.9	23.8	4.8	2.8	3.6	4.1	2.0	0.6	5.9
V	3	1	H	50	0.880	44	31.6	35.0	13.5	9.1	4.3	5.1	4.4	0.8	3.5
V	3	1	P	43	0.907	39	0.0	30.3	8.3	0.0	0.0	4.5	8.3	4.5	30.3
V	3	1	W	55	0.636	35	18.7	22.7	6.5	4.1	3.8	4.6	2.4	0.9	4.0
V	3	2	H	50	0.960	48	37.6	40.0	19.0	13.3	4.6	5.6	5.7	1.0	2.3
V	3	2	P	48	0.625	30	0.0	59.2	29.9	0.0	0.0	6.3	29.9	6.3	59.2
V	3	2	W	53	0.660	35	19.7	25.7	7.6	4.9	4.5	5.0	2.7	0.5	6.0
V	3	3	H	60	0.917	55	32.0	38.3	24.7	10.7	4.4	6.2	14.0	1.9	6.3
V	3	3	P	49	0.633	31	0.0	141.4	447.2	0.0	0.0	16.8	447.2	16.8	141.4
V	3	3	W	52	0.654	34	19.3	24.5	8.5	5.0	4.6	5.4	3.5	0.8	5.3
W	1	1	H	48	0.833	40	32.2	33.2	12.1	8.4	4.5	5.4	3.7	0.9	1.0
W	1	1	P	42	0.238	10	0.0	22.3	2.4	0.0	0.0	3.1	2.4	3.1	22.3
W	1	1	W	47	0.340	16	17.1	24.6	7.5	4.5	4.4	4.9	3.0	0.5	7.5
W	1	2	H	50	0.980	49	35.9	39.7	21.9	12.7	4.6	6.1	9.1	1.5	3.8
W	1	2	P	51	0.647	33	0.0	71.2	55.8	0.0	0.0	7.8	55.8	7.8	71.2
W	1	2	W	57	0.526	30	17.1	28.9	7.6	3.4	4.1	4.8	4.2	0.7	11.8
W	1	3	H	48	0.688	33	26.6	38.4	22.5	4.5	3.4	6.2	18.0	2.7	11.8
W	1	3	P	56	0.268	15	0.0	74.8	93.0	0.0	0.0	9.7	93.0	9.7	74.8
W	1	3	W	48	0.396	19	17.6	23.9	5.1	2.4	3.4	4.3	2.8	0.9	6.3
W	2	1	H	49	0.735	36	30.3	30.2	8.2	6.0	3.8	4.7	2.2	0.9	-0.1
W	2	1	P	47	0.362	17	0.0	22.5	2.7	0.0	0.0	3.1	2.7	3.1	22.5
W	2	1	W	49	0.286	14	20.2	24.1	4.7	3.0	3.6	4.2	1.6	0.6	3.9
W	2	2	H	53	0.906	48	38.4	41.5	19.7	12.1	4.3	5.6	7.6	1.3	3.1
W	2	2	P	62	0.532	33	0.0	57.9	41.6	0.0	0.0	6.7	41.6	6.7	57.9
W	2	2	W	45	0.467	21	21.0	27.6	9.0	5.6	4.5	5.1	3.4	0.6	6.7
W	2	3	H	48	0.729	35	28.5	35.7	13.8	7.0	4.0	5.5	6.8	1.4	7.2
W	2	3	P	57	0.368	21	0.0	49.5	32.1	0.0	0.0	6.8	32.1	6.8	49.5
W	2	3	W	46	0.283	13	16.3	22.0	3.3	1.7	3.0	3.6	1.6	0.7	5.7
W	3	1	H	45	0.778	35	39.0	33.8	14.9	14.0	4.7	5.6	0.9	0.9	-5.1
W	3	1	P	46	0.370	17	0.0	22.3	3.3	0.0	0.0	3.1	3.3	3.1	22.3
W	3	1	W	48	0.604	29	21.5	26.7	6.5	4.3	4.0	4.4	2.2	0.3	5.2
W	3	2	H	56	0.929	52	31.6	34.5	11.2	6.1	3.7	5.1	5.1	1.4	2.9
W	3	2	P	52	0.692	36	0.0	51.6	32.4	0.0	0.0	6.3	32.4	6.3	51.6
W	3	2	W	49	0.510	25	20.0	28.1	10.3	5.3	4.6	5.5	5.0	0.9	8.1
W	3	3	H	52	0.635	33	31.3	35.4	12.9	6.6	4.1	5.5	6.3	1.4	4.0
W	3	3	P	51	0.176	9	0.0	48.4	30.2	0.0	0.0	6.0	30.2	6.0	48.4
W	3	3	W	61	0.311	19	17.3	22.8	7.1	3.1	3.9	5.1	4.1	1.1	5.5

APPENDIX D:

PLOT LEVEL DATA FOR INDIVIDUAL HARDWOOD SPECIES ASSOCIATED WITH CHAPTER III

Column Heading	Description
Site	O=Ohio, W=West Virginia, V=Virginia
Block	Block # at each site as indicated on site maps
Trt	Treatments: 1=weed control only, 2=weed control plus tillage, 3=weed control plus tillage plus fertilization
Grp	Hardwood Species Group (See below)
Hti	Initial height measured at beginning of growing season (end of May, 2004)
Htf	Final height measured late August, 2004
Diami	Initial diameter
Diamf	Final diameter
Vi	Initial Volume (Diameter squared times height)
Vf	Final Volume
Vgrow	Volume Growth (Final Vol.-Initial Vol.)
Dgrow	Diameter Growth
Hgrow	Height Growth
Avgsurv	Average Survival Percentage
n	Number of observations
	No observations for growth due to zero survival
	No observations for survival or growth due to no shrubs in measurement plot

site	block	trt	grp	n (survival)	avgsurv	n (growth)	hti	htf	vf	vi	diami	diamf	vgrow	dgrow	hgorw
O	1	1	other	25	0.640	16	25.9	24.6	4.9	3.4	3.3	4.0	1.5	0.8	-1.3
O	1	1	shrub	8	0.625	5	27.4	29.2	8.6	3.4	3.4	5.0	5.3	1.6	1.8
O	1	1	timber	12	0.667	8	38.0	36.5	25.2	16.7	5.0	5.9	8.5	1.0	-1.5
O	1	2	other	22	0.955	21	25.9	23.5	4.9	4.1	3.8	4.3	0.7	0.5	-2.3
O	1	2	shrub	15	0.867	13	34.8	40.4	12.3	6.9	3.5	5.0	5.4	1.5	5.5
O	1	2	timber	14	1.000	14	36.6	34.8	20.0	9.8	4.6	5.9	10.3	1.3	-1.9
O	1	3	other	20	0.400	8	23.0	21.8	4.7	4.4	3.9	4.1	0.2	0.2	-1.3
O	1	3	shrub	6	0.000	0	.	.	.	.	.	.	.	.	.
O	1	3	timber	21	0.333	7	33.7	37.0	10.6	9.6	4.8	4.9	1.0	0.1	3.3
O	2	1	other	13	0.923	12	27.3	27.4	7.7	4.7	4.0	4.9	3.0	0.9	0.1
O	2	1	shrub	19	0.526	10	30.1	34.1	12.3	5.7	3.4	5.4	6.6	2.0	4.0
O	2	1	timber	19	0.842	16	52.9	52.8	43.6	32.2	7.3	8.3	11.5	1.0	-0.1
O	2	2	other	19	0.632	12	19.6	17.6	2.3	2.1	3.1	3.3	0.2	0.2	-2.0
O	2	2	shrub	18	0.333	6	23.7	26.8	5.3	2.0	2.7	4.4	3.3	1.7	3.2
O	2	2	timber	14	0.286	4	50.0	24.8	12.5	15.9	5.3	5.9	-3.3	0.7	-25.3
O	2	3	other	26	0.038	1	30.0	32.0	3.9	3.1	3.2	3.5	0.8	0.3	2.0
O	2	3	shrub	7	0.000	0	.	.	.	.	.	.	.	.	.
O	2	3	timber	21	0.048	1	76.0	76.0	61.6	60.2	8.9	9.0	1.4	0.1	0.0
O	3	1	other	18	0.444	8	22.6	20.9	5.0	4.8	3.9	4.5	0.2	0.5	-1.8
O	3	1	shrub	13	0.308	4	27.3	23.0	4.6	3.6	3.6	4.2	1.0	0.5	-4.3
O	3	1	timber	15	0.467	7	31.9	27.9	9.6	8.8	4.4	5.1	0.8	0.7	-4.0
O	3	2	other	27	0.889	24	26.5	21.2	4.8	3.6	3.5	4.2	1.1	0.7	-5.3
O	3	2	shrub	12	0.750	9	27.0	25.8	8.3	4.8	3.4	4.2	3.5	0.8	-1.2
O	3	2	timber	14	0.643	9	35.1	21.8	6.5	9.6	4.8	5.4	-3.1	0.5	-13.3
O	3	3	other	19	0.368	7	29.3	22.1	4.0	4.4	3.5	4.0	-0.4	0.5	-7.1
O	3	3	shrub	0	.	0	.	.	.	.	.	.	.	.	.
O	3	3	timber	27	0.074	2	27.5	13.5	3.2	6.2	4.2	4.6	-3.1	0.4	-14.0
V	1	1	other	26	1.000	26	24.1	27.1	8.0	4.5	4.0	4.7	3.4	0.7	3.0

site	block	trt	grp	n (survival)	avgsurv	n (growth)	hti	htf	vf	vi	diami	diamf	vgrow	dgrow	hgorw
V	1	1	shrub	17	0.882	15	31.1	36.3	12.0	9.3	3.6	5.1	2.8	1.5	5.2
V	1	1	timber	7	1.000	7	36.0	35.6	10.5	8.2	4.4	5.0	2.2	0.6	-0.4
V	1	2	other	19	1.000	19	23.3	25.9	8.3	3.8	4.0	5.0	4.4	1.0	2.7
V	1	2	shrub	15	0.933	14	36.6	47.4	17.0	8.5	3.6	5.6	8.5	1.9	10.9
V	1	2	timber	15	1.000	15	35.5	36.5	18.7	11.5	4.8	5.9	7.2	1.1	1.0
V	1	3	other	19	1.000	19	27.9	39.8	37.9	6.1	4.4	8.5	31.9	4.0	11.8
V	1	3	shrub	8	1.000	8	34.9	54.0	24.5	7.4	3.7	6.6	17.1	2.9	19.1
V	1	3	timber	17	0.941	16	44.4	46.1	28.6	15.7	5.4	6.9	12.9	1.5	1.6
V	2	1	other	18	0.833	15	25.0	26.5	8.7	6.5	4.5	4.8	2.2	0.4	1.5
V	2	1	shrub	17	0.471	8	25.3	39.3	17.8	6.5	3.6	5.3	11.3	1.7	14.0
V	2	1	timber	23	0.522	12	35.3	37.2	9.4	6.8	4.0	4.6	2.6	0.6	1.9
V	2	2	other	18	0.889	16	24.3	29.7	18.2	5.3	4.0	5.7	12.8	1.7	5.4
V	2	2	shrub	12	0.750	9	40.6	55.3	38.7	13.7	4.5	7.3	25.0	2.7	14.8
V	2	2	timber	23	0.652	15	32.0	29.8	10.2	6.1	3.6	5.0	4.1	1.4	-2.2
V	2	3	other	25	0.760	19	24.5	28.9	16.4	4.1	3.8	5.3	12.3	1.5	4.4
V	2	3	shrub	13	0.538	7	32.1	55.1	32.2	12.3	4.5	6.9	19.9	2.5	23.0
V	2	3	timber	13	0.462	6	48.3	50.7	22.6	13.7	5.0	6.3	9.0	1.3	2.3
V	3	1	other	23	0.913	21	26.6	30.1	9.7	6.0	4.3	5.0	3.6	0.7	3.5
V	3	1	shrub	11	0.727	8	29.3	33.8	16.0	12.0	3.4	4.5	4.0	1.1	4.5
V	3	1	timber	16	0.938	15	39.8	42.7	17.7	11.9	4.8	5.7	5.8	0.9	2.9
V	3	2	other	18	1.000	18	22.7	25.9	9.8	4.9	3.7	4.6	4.9	0.9	3.3
V	3	2	shrub	7	1.000	7	53.9	55.7	33.5	26.1	5.0	6.1	7.4	1.1	1.9
V	3	2	timber	25	0.920	23	44.4	46.1	21.9	16.0	5.1	6.2	5.8	1.1	1.7
V	3	3	other	22	0.909	20	24.3	30.3	26.0	6.1	3.9	6.2	19.9	2.3	6.0
V	3	3	shrub	11	0.818	9	33.7	50.6	28.8	9.4	3.8	6.9	19.4	3.0	16.9
V	3	3	timber	27	0.963	26	37.4	40.3	22.2	14.7	4.9	6.0	7.5	1.1	2.9
W	1	1	other	13	0.923	12	29.1	31.8	16.7	9.9	5.4	6.8	6.8	1.4	2.8
W	1	1	shrub	9	0.889	8	32.0	34.0	6.1	4.1	2.7	3.9	2.0	1.2	2.0
W	1	1	timber	26	0.769	20	34.1	33.7	11.7	9.3	4.7	5.1	2.4	0.4	-0.4
W	1	2	other	15	1.000	15	24.5	33.1	16.4	4.3	4.1	6.2	12.1	2.1	8.7
W	1	2	shrub	14	1.000	14	36.8	45.3	21.6	14.8	3.9	5.5	6.8	1.5	8.5
W	1	2	timber	21	0.952	20	43.9	40.7	26.1	17.6	5.5	6.5	8.6	1.0	-3.2
W	1	3	other	22	0.864	19	24.7	42.6	27.7	3.5	3.5	7.0	24.2	3.6	17.9
W	1	3	shrub	12	0.333	4	20.3	27.8	7.7	2.3	2.4	4.1	5.4	1.7	7.5
W	1	3	timber	14	0.714	10	32.7	34.6	18.6	7.2	3.8	5.4	11.4	1.5	1.9
W	2	1	other	18	0.889	16	26.5	30.0	8.0	4.2	3.7	4.8	3.8	1.1	3.5
W	2	1	shrub	9	0.778	7	23.4	28.3	4.7	1.9	2.5	4.0	2.8	1.5	4.9
W	2	1	timber	22	0.591	13	38.7	31.5	10.2	10.4	4.6	4.9	-0.2	0.3	-7.2
W	2	2	other	19	0.895	17	27.2	30.9	9.6	2.9	3.1	5.0	6.7	1.9	3.8
W	2	2	shrub	9	0.889	8	47.6	48.0	25.2	21.8	5.0	5.4	3.4	0.5	0.4
W	2	2	timber	25	0.920	23	43.6	47.1	25.2	15.5	5.0	6.2	9.7	1.2	3.5
W	2	3	other	22	0.818	18	24.0	32.8	12.7	4.2	3.6	5.2	8.5	1.6	8.8
W	2	3	shrub	8	0.375	3	36.3	47.3	19.6	20.1	5.1	5.9	-0.4	0.8	11.0
W	2	3	timber	18	0.778	14	32.6	37.1	14.0	7.8	4.3	5.7	6.2	1.4	4.4
W	3	1	other	16	0.813	13	26.5	29.2	11.7	6.0	4.3	5.7	5.7	1.5	2.7
W	3	1	shrub	12	0.750	9	44.7	35.4	16.6	19.4	4.4	5.4	-2.8	1.0	-9.2
W	3	1	timber	17	0.765	13	47.5	37.4	16.9	18.2	5.3	5.5	-1.2	0.2	-10.2
W	3	2	other	16	1.000	16	24.8	32.9	9.0	2.7	3.1	4.9	6.2	1.8	8.1
W	3	2	shrub	10	0.900	9	38.9	42.0	16.4	11.1	4.1	5.1	5.3	1.0	3.1
W	3	2	timber	30	0.900	27	33.2	32.9	10.8	6.5	3.9	5.2	4.3	1.2	-0.3
W	3	3	other	18	0.889	16	22.9	28.6	11.4	3.6	3.9	5.7	7.7	1.8	5.7
W	3	3	shrub	9	0.333	3	21.0	29.7	5.8	1.2	2.4	3.7	4.6	1.3	8.7
W	3	3	timber	25	0.560	14	43.1	44.3	16.2	11.3	4.7	5.6	4.9	0.9	1.1

APPENDIX E:
PLOT LEVEL DATA FOR HYBRID POPLAR BIOMASS, FOLIAR NUTRIENTS, AND MOISTURE STRESS ASSOCIATED WITH CHAPTER III

Biomass

Block	Block # corresponds to WV site maps
Trt	Treatment: F=weed control, tillage, and fertilization, R=weed control and tillage, U=weed control only
#	Sample tree # within each plot
leafbio	leaf biomass (g)
frootbio	fine root biomass (g) for roots <0.5mm in diameter
crootbio	coarse root biomass (g) for roots >0.5mm
totrootbio	Total root biomass (fine+coarse)
percentfroots	Percentage of fine roots
percentcroots	Percentage of coarse roots
stem	Stem biomass (g)
stembio	Stem plus plug biomass
shoot bio	Stembio plus leafbio
rootshootratio	
rootleafratio	

Block	Trt	leafbio	frootbio	crootbio	totrootbio	stembio	shootbio	rootshootratio	rootleafratio	percentfroots	percentcroots
1	F	32.00	6.29	31.04	37.33	51.08	83.08	0.36	0.96	0.24	0.76
1	R	16.06	2.79	10.69	13.48	20.82	36.88	0.36	0.83	0.20	0.80
1	U	3.82	0.45	1.12	1.57	16.66	20.48	0.07	0.38	0.40	0.60
2	F	27.89	6.53	24.76	31.29	51.68	79.58	0.34	0.98	0.25	0.75
2	R	15.91	1.74	7.18	8.92	21.82	37.72	0.23	0.57	0.20	0.80
2	U	2.42	0.31	0.90	1.21	10.23	12.65	0.07	0.33	0.64	0.36
3	F	24.37	3.46	13.20	16.66	41.29	65.65	0.24	0.68	0.21	0.79
3	R	10.56	1.89	8.29	10.18	20.02	30.58	0.23	0.82	0.31	0.69
3	U	1.91	0.32	0.24	0.56	8.67	10.58	0.05	0.30	0.57	0.43

Foliar Nutrients

part	Tissue type: L=Foliage, R=Root, S=Stem
block	Block # corresponds to block number on site maps
trt	Treatment: F=weed control, tillage, and fertilization, R=weed control and tillage, U=weed control only
Ca, K, …..	Elemental conc. (mg/g) based on a composite sample (equal weight) of the three sample trees per plot

part	block	trt	Ca	K	Mg	P	S	Zn	B	Cu	Mn
L	1	F	13.385	16.400	5.018	2.215	4.163	0.040	0.029	0.009	0.273
L	1	R	13.954	15.909	4.394	1.780	4.919	0.070	0.030	0.010	0.146
L	1	U	14.891	13.851	4.926	1.926	4.688	0.092	0.025	0.010	0.118
L	2	F	11.494	18.259	5.320	2.330	4.649	0.080	0.072	0.015	0.310
L	2	R	10.824	16.274	5.423	2.057	5.245	0.105	0.025	0.010	0.114
L	2	U	10.471	13.595	4.256	1.912	4.223	0.070	0.022	0.008	0.093
L	3	F	10.971	17.167	5.002	2.411	4.438	0.134	0.040	0.009	0.347
L	3	R	11.993	15.495	4.777	1.957	4.284	0.102	0.025	0.009	0.143
L	3	U	11.056	15.117	4.612	2.110	2.858	0.091	0.043	0.009	0.272
R	1	F	8.949	9.732	2.354	1.037					
R	1	R	9.010	10.637	1.879	0.771					
R	1	U	7.768	8.275	1.819	0.986					
R	2	F	7.561	12.159	2.270	1.126					
R	2	R	5.724	11.030	1.858	0.802					
R	2	U	6.198	10.405	1.929	1.039					
R	3	F	6.126	9.999	1.420	1.480					
R	3	R	7.111	10.271	1.633	1.287					
R	3	U	4.941	7.349	1.657	1.162					
S	1	F	1.041	1.668	0.440	0.222					
S	1	R	1.278	1.682	0.436	0.173					
S	1	U	0.934	1.614	0.326	0.215					
S	2	F	0.857	1.600	0.347	0.205					
S	2	R	1.117	2.347	0.540	0.240					
S	2	U	1.964	4.455	0.749	0.609					
S	3	F	1.054	1.871	0.448	0.319					
S	3	R	1.361	2.379	0.548	0.315					
S	3	U	1.208	2.204	0.445	0.297					

Foliar C and N

part	Tissue type: L=Foliage, R=Root, S=Stem
block	Block # corresponds to block number on site maps
trt	Treatment: F=weed control, tillage, and fertilization, R=weed control and tillage, U=weed control only
C and N	Elemental conc. (%) based on a composite sample (equal weight) of the three sample trees per plot

part	trt	block	c	n
L	F	1	53.16562	3.496906
L	F	2	52.83212	3.247168
L	F	3	52.51042	3.028877
L	R	1	53.14971	2.835552
L	R	2	52.75518	2.668754
L	R	3	52.57773	2.323796
L	U	1	50.42553	2.457781
L	U	2	50.8819	2.49584
L	U	3	52.83946	2.294324
R	F	1	47.77343	1.223173
R	F	2	47.95268	1.095721
R	F	3	48.09924	1.058564
R	R	1	47.67916	0.873925
R	R	2	48.85468	0.811024
R	R	3	47.42647	0.678054
R	U	1	45.33124	0.994152
R	U	2	45.08512	0.76132
R	U	3	42.57222	1.059525
S	F	1	53.31195	0.859249
S	F	2	53.59706	0.830817
S	F	3	53.84133	0.808818
S	R	1	53.11254	0.790642
S	R	2	52.62985	0.764107
S	R	3	53.1286	0.665423
S	U	1	52.88493	0.812103
S	U	2	50.71754	0.691941
S	U	3	53.19978	0.643115

Moisture Stress

Date	Dates were August 16-19, 2004
wp	Plant water potential
sm	gravimetric soil moisture

Block	Trt	Date	wp	sm
1	1	16	16.05	.
1	1	17	14.90	15.37
1	1	18	19.50	15.47
1	1	19	15.75	12.00
1	2	16	14.40	.
1	2	17	17.90	15.65
1	2	18	21.00	12.97
1	2	19	24.00	11.40
1	3	16	12.35	.
1	3	17	16.60	14.37
1	3	18	17.05	12.05
1	3	19	17.50	13.19
2	1	16	13.45	.
2	1	17	17.80	15.93
2	1	18	18.45	13.27
2	1	19	15.45	10.65
2	2	16	12.10	.
2	2	17	18.45	10.57
2	2	18	20.00	11.22
2	2	19	23.80	11.45
2	3	16	12.60	.
2	3	17	18.65	15.59
2	3	18	21.65	13.03
2	3	19	17.95	11.38
3	1	16	12.15	.
3	1	17	14.30	16.12
3	1	18	17.35	15.25
3	1	19	16.40	12.39
3	2	16	13.50	.
3	2	17	17.10	15.32
3	2	18	17.50	13.78
3	2	19	18.15	11.93
3	3	16	11.00	.
3	3	17	18.00	15.16
3	3	18	19.60	11.60
3	3	19	18.30	11.30

APPENDIX F: PLOT LEVEL DATA ASSOCIATED WITH CHAPTER IV

Block	See map
trt	Thinned (T) or Unthinned (U)
age	26 or projected to age 30 using stand table projection
propsawstems	Proportion of trees/acre in sawtimber size class (11.1in and up)
propsawvol	Proportion of stand volume in sawtimber
cuftac	Cubic foot volume per acre
tonsac	Tons of pulpwood per acre
bdftac	Boardfoot volume per acre
pulpvalac	Value of pulpwood per acre
sawvalac	Value of sawtimber per acre
baac	Basal area per acre
voltree	Cubic foot volume per tree
dbh	Average dbh
tpa	Average trees per acre
ht	Average total height

block	trt	age	propsawstems	propsawvol	cuftac	tonsac	bdftac	pulpvalac	sawvalac	totvalac	baac	voltree	dbh	tpa	ht
1	T	26	0.727	0.869	5281	19.3	22772	139	3393	3532	186	24.0	12.2	220	67.3
2	T	26	0.545	0.734	3881	28.8	13627	208	2030	2238	154	17.6	11.1	220	60.4
3	T	26	0.167	0.263	3256	66.8	4010	482	598	1080	129	13.6	9.8	240	61.8
1	U	26	0.389	0.708	5778	47.1	20353	340	3033	3372	221	16.0	10.1	360	59.9
2	U	26	0.250	0.493	4590	64.9	10706	468	1595	2063	195	11.5	9.1	400	54.8
3	U	26	0.250	0.445	3040	47.0	5914	339	881	1220	137	9.5	8.5	320	52.8
1	T	30	0.909	0.974	8040	5.9	40644	42	5771	5814	247	36.5	14.0	220	76.8
2	T	30	0.818	0.936	6428	11.5	30587	83	4343	4426	219	29.2	13.2	220	69.5
3	T	30	0.750	0.861	5494	21.2	23122	153	3283	3436	187	22.9	11.8	240	71.1
1	U	30	0.389	0.713	8265	66.2	30835	477	4379	4856	272	23.0	11.2	360	69.0
2	U	30	0.350	0.633	6793	69.6	21567	502	3062	3564	247	17.0	10.2	400	63.3
3	U	30	0.375	0.629	4531	46.9	13627	338	1935	2273	174	14.2	9.5	320	61.1

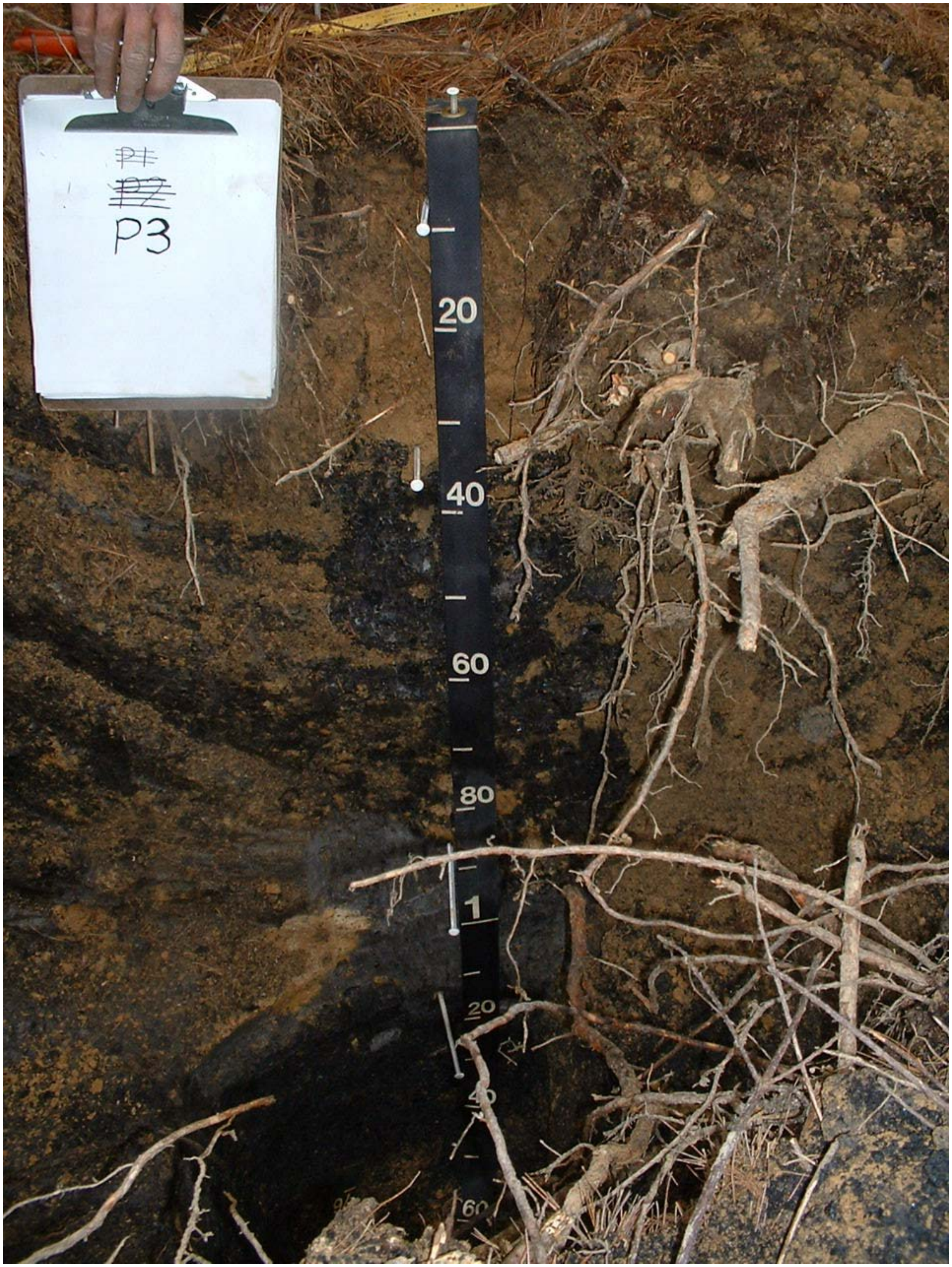
APPENDIX G:

SOIL PROFILE PICTURES FOR A WHITE PINE STAND GROWING ON A PRE-SMCRA SURFACE MINE IN WISE COUNTY, VIRGINIA

Pit 1

Pit 2

Pit 3



Pit 4

Pit 5

Pit 6

Pit 7

Pit 8

Pit 9

Pit 10

Pit 11

Pit 12

Pit 13

Pit 14

Pit 15

Pit 16

Pit 17

Pit 18

Pit 19

Pit 20

Pit 21

Pit 22

Pit 23

Pit 24

Pit 25

Pit 26

Pit 27

APPENDIX H:

SOIL PROFILE DESCRIPTIONS FOR THE WHITE PINE STAND IN WISE COUNTY, VIRGINIA

Abbreviations:

Horizon Boundary
- a = abrupt
- c = clear
- g = gradual
- d = diffuse

Structure

Shape:
- sbk = sub-angular blocky
- pl = platy
- ms = massive

Grade:
- 0 = structureless
- 1 = weak

Texture
- LS = loamy sand
- SL = sandy loam
- L = loam
- SiL = silt loam
- Si = silt
- SiCL = silty clay loam
- CL = clay loam
- SCL = sandy clay loam
- SC = sandy clay
- C = clay

Roots

Quantity
- vf = very few
- f = few
- mf =moderately few
- c = common
- m = many

Size Class
- very fine, <1mm
- fine, 1-2mm
- medium, 2-5mm
- coarse, 5-10mm

Very Coarse, >10mmPit	Bottom Depth	Horizon	Horizon Boundary	Color			Structure		Texture	Consistence	Roots				
				Hue	Value	Chroma	Shape	Grade			Very Coarse	Coarse	Medium	Fine	Very Fine
1	9	A	a	10YR	3	3	gr	1	L	vfr	mf	c	m	m	m
	32	Bw	c	10YR	5	6	pl	1	SL	fr	vf	mf	mf	c	m
	49	2C1	a	N	2.5	.	ms	.	gr SL	fr	vf	mf	mf	c	c
	188	3C2	a	10YR	5	4	ms	.	gr L	fi	.	c	m	m	m
2	2	A	a	10YR	3	2	gr	1	L	vfr					
	15	Bw	a	10YR	5	4	sbk	1	SL	vfr	f	c	m	m	m
	73	2C1	d	10YR	5	4	ms	0	L	fr	f	f	c	m	m
	173	2C2	.	2.5Y	3	1	ms	0	L	fr	.	.	f	f	f
	173+	R													
3	8	A	a	10YR	4	2	sbk	1	SL	vfr	f	f	m	m	m
	33	Bw	a	10YR	4	6	sbk	1	SL	vfr	mf	mf	m	m	m
	88	2C1	a	2.5Y	4	1	ms	0	gr SL	fr	.	.	.	f	f
	113	3Cd	a	2.5Y	5	1	ms	0	CL	fi	.	.	.	.	.
	163+	4C3		BLACK	.	.	ms	0	gr LS	vfr	.	.	.	.	.
4	5	A	a	10YR	3	1	sbk	1	SL	vfr	.	.	.	f	m
	37	Bw	a	10YR	5	4	sbk	1	SL	vfr	mf	c	m	m	m
	83	2C1	a	N	2.5	.	ms	0	SL	vfr	f	f	c	c	m
	98	3C2	a	2.5Y	5	1	pl	1	SiC	vfi	.	f	f	f	f
	108	4C3	a	10YR	6	3	pl	2	SiCL	fi	.	.	f	f	f
	169	5C4	a	BLACK	.	.	ms	0	SL	vfr	.	.	.	f	.
	169+	R													
5	7	A	c	10YR	4	3	sbk	1	SL	vfr					
	24	Bw	d	10YR	5	4	sbk	1	SL	vfr	mf	mf	m	m	m
	87	C1	a	10YR	5	6	ms	0	SL	vfr	.	.	c	c	c
	153	2C2	a	10YR	3	2	ms	0	SL	fr	.	.	.	.	.
	190+	R													

Pit	Bottom Depth	Horizon	Horizon Boundary	Color			Structure		Texture	Consistence	Roots				
				Hue	Value	Chroma	Shape	Grade			Very Coarse	Coarse	Medium	Fine	Very Fine
6	38	Bw	d	10YR	5	6	sbk	1	SL	vfr	m	m	m	m	m
	75	C1	a	10YR	5	6	ms	0	SL	vfr	f	.	f	c	c
	176	2C2	c	2.5Y	2.5	1	ms	0	L	fr	.	.	f	mf	mf
	195	3C3	.	BLACK	.	.	ms	0	COAL DUST	vfr	.	.	.	.	.
	195+	R													
7	6	A		10YR	4	3	sbk	1	SL	vfr	.	.	c	m	m
	36	Bw		10YR	5	6	sbk	1	SL	vfr	mf	mf	c	m	m
	70	C1		10YR	5	6	ms	0	SL	vfr	.	.	f	c	c
	99	2C2		2.5Y	3	1	ms	0	L	fr	.	.	mf	mf	c
	173	3C3		10YR	4	3	ms	0	SL	fr	.	.	mf	mf	mf
	173+	R													
8	3	A	c	10YR	4	3	sbk	1	SL	vfr					
	32	Bw	d	10YR	5	6	sbk	1	SL	vfr	mf	mf	m	m	m
	97	C1	a	10YR	5	6	ma	0	SL	vfr	.	.	m	m	m
	139	2C2	a	2.5Y	2.5	1	ma	0	L	fr	.	.	mf	m	m
	139+	R													
9	4	A	c	10YR	4	3	sbk	1	SL	vfr					
	23	Bw	d	10YR	5	4	sbk	1	SL	vfr	mf	mf	m	m	m
	87	C1	a	10YR	5	6	ms	0	SL	vfr	.	.	c	c	c
	133	2C2	a	10YR	3	2	ms	0	SL	fr	.	.	.	.	.
	133+	R													
10	5	A	c	10YR	4	3	sbk	1	SL	vfr					
	29	Bw	a	10YR	5	4	sbk	1	SL	vfr	f	c	m	m	m
	127	2C1	c	2.5Y	4	1	ms	0	SiL	fr	.	.	mf	m	m
	172	2C2	a	2.5Y	4	1	ms	0	CL	fi	.	.	.	.	.
	172+	R													

Pit	Bottom Depth	Horizon	Horizon Boundary	Color			Structure		Texture	Consistence	Roots				
				Hue	Value	Chroma	Shape	Grade			Very Coarse	Coarse	Medium	Fine	Very Fine
11	5	A	c	10YR	3	2	sbk	1	SL	vfr					
	31	Bw	g	10YR	5	4	sbk	1	SL	vfr	c	c	m	m	m
	54	C1	a	10YR	4	4	ms	0	SL	vfr	mf	f	c	c	c
	145	2C2	a	2.5Y	3	1	ms	0	gr SL	vfr	.	f	mf	m	m
	145+	R													
12	3	A	c	10YR	4	4	sbk	1	SL	vfr					
	23	Bw	a	10YR	5	4	sbk	1	SL	vfr	mf	c	m	m	m
	38	2C1	c	10YR	3	1	ms	0	L	fr	.	c	m	m	m
	103	2C2	c	2.5Y	3	1	ms	0	L/CL	fr	.	.	.	c	m
	169	2C3	g	2.5Y	2.5	1	ms	0	L/CL	fr	.	.	f	c	c
	195	2C4	.	2.5Y	4	1	ms	0	CL	fi	.	.	.	.	.
	195+	R													
13	3	A	c	10YR	4	3	sbk	1	SL	vfr					
	50	Bw	a	10YR	5	4	sbk	1	SL/L	fr	c	m	m	m	m
	87	2C1	a	N	2.5	.	ms	0	SiL	fi	.	.	f	m	m
	112	3C2	c	2.5Y	5	2	ms/pl	0	SiC	efi	.	.	.	f	.
	138	4C3	a	10YR	6	6	ms/pl	0	SiC	vfi	.	.	f	f	f
	192	5C4	a	BLACK	.	.	ms	0	SiL/L	vfr	.	.	c	c	c
	192+	R													
14	8	A	a	10YR	4	3	sbk	1	SL	vfr	c	m	m	m	m
	19	2C1	a	2.5Y	4	1	ms	0	L	fi	mf	mf	m	m	m
	103	3C2	c	10YR	5	4	ms	0	gr SL	fr	f	f	m	m	m
	190+	3C3	.	10YR	5	4	ms	0	ecb SL	vfr	f	f	m	m	m

Pit	Bottom Depth	Horizon	Horizon Boundary	Color			Structure		Texture	Consistence	Roots				
				Hue	Value	Chroma	Shape	Grade			Very Coarse	Coarse	Medium	Fine	Very Fine
15	4	A	c	10YR	4	3	sbk	1	SL	vfr					
	32	Bw	a	10YR	4	6	sbk	1	SL	vfr	mf	c	m	m	m
	90	2C1	a	10YR	3	3	ms	0	SL	fr	.	.	.	c	c
	153	3C2	a	10YR	5	6	ms	0	SL	fr	.	.	.	.	.
	181	4C3	a	N	2.5	.	ms	0	SiL	vfr	.	.	.	.	.
	181+	R													
16	3	A	c	10YR	4	3	sbk	1	SL	vfr					
	25	Bw	g	10YR	4	6	sbk	1	SL	fr	c	c	m	m	m
	87	C1	d	10YR	5	6	ms	0	SL	fr	f	f	mf	c	m
	177	C2	a	10YR	5	4	ms	0	SL	fr	.	.	m	m	m
	222+	2C3	.	10YR	3	2	ms	0	SL	fr	.	.	.	m	m
17	3	A	g	10YR	3	2	sbk	1	SL	vfr					
	31	C1	a	10YR	3	2	ms	0	gr SL	fr	.	.	m	m	m
	43	2C2	a	10YR	4	4	ms	0	SL	vfr	mf	mf	m	m	m
	85	3C3	a	N	2.5	.	ms	0	gr L	vfr	.	.	f	mf	mf
	200+	4C4	.	10YR	5	4	ms	0	gr SL	fr	.	.	f	mf	mf
18	3	A	g	10YR	4	3	sbk	1	SL	vfr					
	20	Bw	c	10YR	4	4	sbk	1	SL	vfr	m	f	m	m	m
	38	C1	a	10YR	5	6	ms	0	SL	vfr	f	mf	m	m	m
	55	2C2	c	10YR	3	2	ms	0	SL	vfr	.	.	c	m	m
	93	3C3	a	5Y	2.5	1	ms	0	SiCL	fr	.	.	mf	m	m
	200+	4C4	.	10YR	5	6	ms	0	SL	fr	.	.	.	mf	c
19	3	A	c	10YR	4	3	sbk	1	LS	vfr					
	19	C	a	10YR	5	6	ms	0	LS	vfr	m	m	m	m	m
	132+	Cr	.	10YR	5	6	ms	0	SL	vfi	.	.	f	f	f

Pit	Bottom Depth	Horizon	Horizon Boundary	Color			Structure		Texture	Consistence	Roots				
				Hue	Value	Chroma	Shape	Grade			Very Coarse	Coarse	Medium	Fine	Very Fine
20	4	A	c	10YR	4	3	sbk	1	SL	vfr					
	22	C	a	10YR	5	6	ms	0	SL	vfr	c	c	m	m	m
	22+	Cr	.	.	.	.	.	.	.	.	.	.	.	v	v
21	2	A	c	10YR	4	3	sbk	1	LS	vfr					
	13	C	c	10YR	5	6	ms	0	LS	vfr	mf	c	m	m	m
	24	Cr	a	.	.	.	.	.	.	.	.	.	f	f	mf
	24+	R													
22	3	A	c	10YR	3	2	sbk	1	SL	vfr					
	19	Bw	c	10YR	4	6	sbk	1	SL	vfr	mf	mf	m	m	m
	70	C1	a	10YR	5	6	ms	0	SL	fr	f	f	c	c	c
	139	2C2	a	N	2.5	.	ms	0	L	fr	.	.	.	mf	c
	163	3C3	a	2.5Y	4	1	ms	0	SiC	fi	.	.	.	.	.
	175+	4C4	.	BLACK	.	.	ms	0	LS	vfr	.	.	.	.	.
23	4	A	c	10YR	4	3	sbk	1	SL	vfr					
	27	Bw	d	10YR	5	6	sbk	1	SL	vfr	c	c	m	m	m
	200+	C1	.	10YR	5	6	ms	0	SL	vfr	mf	c	m	m	m
24	2	A	c	10YR	3	3	sbk	1	SL	vfr					
	23	Bw	d	10YR	4	6	sbk	1	gr SL	vfr	c	c	m	m	m
	185+	C	.	10YR	5	6	ms	0	gr SL	vfr	mf	c	m	m	m
25	3	A	c	10YR	4	3	sbk	1	SL	vfr					
	20	Bw	a	10YR	4	6	sbk	1	SL	vfr	mf	c	m	m	m
	38	2C1	a	5Y	4	1	ms	0	SiCL	fi	mf	mf	m	m	m
	174	3C2	a	N	2.5	.	ms	0	gr L	fr	f	f	mf	c	m
	200+	4C3	.	10YR	5	6	ms	0	gr SL	fi	.	.	.	.	.

Pit	Bottom Depth	Horizon	Horizon Boundary	Color			Structure		Texture	Consistence	Roots				
				Hue	Value	Chroma	Shape	Grade			Very Coarse	Coarse	Medium	Fine	Very Fine
26	2	A	c	10YR	4	3	sbk	1	SL	vfr					
	20	Bw	a	10YR	5	6	sbk	1	SL	vfr	c	m	m	m	m
	37	2C1	a	5Y	5	1	ms	0	L	fr	.	mf	m	m	m
	124	3C2	g	10YR	5	6	ms	0	SL	fi	.	f	c	c	c
	194+	3C3	.	10YR	5	4	ms	0	SL	fr	.	f	f	mf	c
27	4	A	c	10YR	4	3	sbk	1	SL	vfr					
	30	Bw	g	10YR	5	6	sbk	1	SL	vfr	mf	c	m	m	m
	200+	C	.	10YR	5	6	ms	0	SL	vfr	f	c	m	m	m

VITA

Chad N. Casselman was born on May 14, 1978, in Jamestown, New York. He received an Associate's Degree in Forest Technology from the New York State Ranger School and a Bachelor's degree from SUNY ESF. He has been happily married to his wife Hillary since 1998 and has two children, Max and Ruby-Kate Casselman, who are ages two and one, respectively.