FIVE-YEAR FERTILIZER AND GROUND COVER EFFECTS ON SURFACE-MINE SOILS AND PINE GROWTH

by

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(ABSTRACT)

During the last three years, 80% of mining permits in Virginia listed forestland as the post-mining land use. Adequate stocking and growth of tree stands at time of bond-release eligibility and beyond is an important beginning for returning mined lands to a productive state. In order to ensure reforestation success, biological constraints, including low mine soil fertility and competition from herbaceous ground cover, must be overcome. The effect of cultural treatments on the growth of three commercial pine species on reclaimed surface-mined land in southwestern Virginia was studied. In June, 1981, containerized seedlings of loblolly (*Pinus taeda L.*), Virginia (*P. virginiana* Mill.), and eastern white (*P. strobus* L.) pines were planted on a flat bench site (Site I) and a site returned to approximate original contour (Site II). Seedlings were artificially inoculated with *Pisolithus tinctorius* ((Pers.) Coker and Couch), fertilized with slow-release fertilizer pellets at time of planting and broadcast with N fertilizer prior to the fourth growing season, and the ground cover around them was controlled with herbicides through the third growing season. Survival and growth of these seedlings after the first and second growing seasons were reported by Schoenholtz and Burger (1984). The response of these pines to treatments at the end of the third and fifth growing seasons were evaluated in this study. Treatment effects on foliar nutrient levels and soil properties were also examined. At the end of five years, loblolly and Virginia pines have been

successfully established and are performing as well as trees in stands growing on natural soils in the southeastern U.S.. Eastern white pine grows slowly the first three years and was just beginning to exhibit a response to treatment. Ground-cover control had the greatest effect on loblolly pine volume-index and elicited as much as an 86% increase in volume-index at the end of five growing seasons. Volume-index of Virginia pine was improved with ground-cover control on Site I and with fertilization on Site II. All species show an additive growth response to the combined treatments. At age five, white pine responded synergistically to combined fertilizer and ground-cover control treatments. The peak response to treatments occurred generally at age two for both loblolly and Virginia pines, while white pine response never peaked. The status of foliar and soil nutrients corroborated the importance of these cultural treatments in improving growth. Negative relationships between volume-index and foliar N and mineralizable N showed that N was not limiting pine growth at this time. Mature stands of serecia lespedeza may have supplied adequate N. A positive relationship between white pine volume-index and foliar P levels suggested that insufficient P may have limited growth of this species. As mine soils in this region age, soil P tends to be fixed by Fe-oxides present in the spoil, making competition for low levels of available-P even greater. Fertilization and ground-cover control will improve tree growth on reforested surface mines by alleviating complex interacting water and nutrient deficiencies. These treatments, implemented during establishment, were still evident at age five, a time that coincides with bond-release elibigility, and response curves suggested that response to treatments will continue as the stands develop.

Dedication

This thesis is dedicated to my parents, , and my brothers and sisters, ; those persons to whom I owe the most but can repay the least.

In Memoriam

John

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All the persons, all the events of your life are there because you have drawn them there. What you choose to do with them is up to you.

Richard Bach

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Introduction

The mining of coal for energy generation is a practice that is centuries old. The commercial mining of coal in the United States, however, is a relatively new procedure, originating in Illinois just 100 years ago (Curtis, 1978). At the present time, questions on the impacts of the practice of surface mining seem to be of minor consequence in comparison to America's demand for a cheap energy supply, a relatively safe means for the extraction of coal, and an income source for many people. Nevertheless, the public has become concerned about our ability to return these drastically disturbed areas to a productive state so that once the land is depleted of its original wealth a renewable resource can be managed in its place. Surface-mine reclamation research was started at a relatively low level in the 1930's by the USDA Central States Forest Experiment Station (Curtis, 1978). Public interest continued to swell and culminated in 1977 with the passage of the Surface Mining Control and Reclamation Act (SMCRA) (Public Law 95-87). This law provided nationwide guidelines for the reclamation of surface-mined lands.

Extraction of bituminous coal from the southern Appalachian region includes seven counties in southwestern Virginia: Buchanan, Dickenson, Lee, Tazewell, Russell, Scott, and Wise. Since the early 1940's, surface mining has disturbed the productive, deciduous forests in this region of Virginia. However, there is limited research dealing with the re-establishment of productive forests on these disturbed sites. Information on mine soil physical, chemical, and biological properties is needed to develop proper establishment techniques. Very little is known about the survival, growth, and productivity of commercial tree species beyond the establishment period and at time of bond-release eligibility (five years after the last reclamation treatment) for lands mined after the passage of SMCRA. Data on the application of cultural treatments to enhance growth is also needed for assessing the feasibility of practicing commercial forestry on these sites.

Recognizing the research needs of southwestern Virginia, Schoenholtz and Burger (1984) and Schoenholtz *et al.* (1987) examined the effects of mycorrhizal inoculation, slow-release fertilizer pellets, and chemical weed control on the establishment of pines on surface-mined sites. They reported first- and second-year responses to these treatments (Schoenholtz and Burger, 1984). This study is a follow-up of their preliminary work. Responses to treatments through age five were measured. In addition, an evaluation of soil properties was made, as well as an examination of how cultural treatments affected mine soil properties. Likely causes of observed treatment effects based on the findings of this study and other reported research were proposed.

The goals of this study were to provide post-establishment reforestation information for surface-mined lands in the coal-producing counties of southwestern Virginia; to examine whether pine plantations continue to respond to cultural treatments applied at time of planting; and to identify mine soil properties affecting reforestation. The specific objectives of this study were:

1. To quantify the performance of loblolly pine (*Pinus taeda* L.), Virginia pine (*Pinus virginiana* Mill.), and eastern white pine (*Pinus strobus* L.) through a five-year establishment period on surface-mined lands in southwestern Virginia.

2. To examine the effects of fertilization and herbaceous ground cover on the performance of these pine species.

3. To compare mine soil physical and chemical properties on a flat bench site (mined prior to enactment of SMCRA) with those on a site returned to approximate original contour (mined after enactment of SMCRA) after five years of tree cover.

4. To evaluate the effects of fertilization and herbaceous ground cover control on mine soil properties.

5. To examine the interactions among pine performance, cultural treatments, and mine soil properties over time.

Literature Review

Introduction

Many researchers have provided information on the success of tree plantings on surface-mined lands (Wade *et al.*, 1985a; Larson and Vimmerstedt, 1983; Ashby *et al.*, 1980; Hart and Byrnes, 1960; Finn, 1958) and on the potential of mine soils to yield wood products (Plass, 1979; Plass and Burton, 1967). However, since the studies reported by these researchers were established, SMCRA was enacted, and some of its requirements may not be conducive to the establishment of productive forestland. For example, one reforestation constraint is the requirement to establish a dense ground cover. Although necessary for erosion control in many circumstances, this ground cover can compete acutely with planted tree seedlings for light, moisture, and nutrients.

The inherently low fertility of mine soils is another reforestation problem. Fertilizer amendments in some form are usually needed, and regulations require nutrients and lime be added as indicated by soil tests and vegetation requirements (Holmberg, 1983; Curtis, 1978). Fertilization of sites after initial fertilization during ground cover establishment reportedly increases the growth rate of trees (Vogel, 1978); however, in some cases, this same fertilizer treatment can increase tree mortality by stimulating herbaceous competition (Czapowskyj, 1973).

The following sections are reviews of the literature on the long-term performance of three commercially important pines (loblolly, Virginia, and eastern white) planted on mine soils, pine response to fertilization and ground cover, changes in mine soil properties mediated by tree cover and cultural treatments, and the interactions among these factors. The way in which the new reclamation law affects the interpretation of the literature is emphasized.

Tree Species Selection and Performance

Parr (1982) suggests two criteria for the selection of forest tree species to be planted on surface-mined lands: 1) acceptable survival and 2) the ability to provide high-quality forest resources and/or wildlife habitat. He also lists four species that meet these requirements in the Midwest: black walnut (*Juglans nigra* L.), white oak (*Quercus alba* L.), autumn olive (*Elaeagnus umbellata* Thumb.), and black locust (*Robinia pseudoacacia* L.). In the northern Appalachian region, more hardwoods have been planted on surface-mined land than in the southern Appalachians. Common hardwood species planted in the northern Appalachians include red maple (*Acer rubrum* L.), silver maple (*Acer saccharinum* L.), river birch (*Betula nigra* L.), green ash (*Fraxinus pennsylvanica* Marsh.), white ash (*Fraxinus americana* L.), sweetgum (*Liquidambar styraciflua* L.) eastern cottonwood (*Populus deltoides* Batr. ex Marsh.), and northern red oak (*Quercus rubra* L.) (Plass, 1978). Coniferous species, such as red pine (*Pinus resinosa* Ait.) and eastern white pine have also been successfully established (Curtis, 1978).

Many conifers, especially pines, have been widely planted for reclamation in the South. In comparison to hardwoods, pines can tolerate soils low in fertility, although hardwoods build a more nutrient rich soil because of high litter nutrient content and rapid turnover. Some of the pine species planted on mined sites in the southern and central Appalachians include Virginia, shortleaf (*Pinus echinata* Mill.), loblolly, pitch (*P. rigida* Mill.), and eastern white pines (Vogel, 1981). Three of these species, loblolly, Virginia, and eastern white pine, were planted in the present study.

USDA Forest Service experiments showed that growth of pines on surface-mined lands in southern and central Appalachia are as good or better than plantings on eroded, abandoned farmlands or other areas with shallow soils (Plass and Burton, 1967). After

20 growing seasons, an average of 126 and 108 m^3/ha of merchantable pulpwood of loblolly and shortleaf pines, respectively, were harvested from plantations established on mined lands in Alabama, illustrating the growth potential of pine trees on spoil. Data on mine soil plantings in Alabama, Tennesee, and Kentucky indicate that loblolly pine grows faster than either shortleaf or Virginia pine, at least during the first five to ten years (Plass and Burton, 1967).

In a trial of 15 tree species located in southwestern Virginia, Torbert *et al.* (1985) found after three growing seasons that the five pine species planted performed better than the 10 hardwood species planted on a site returned to approximate original contour. Of the pines planted, loblolly and Virginia pines grew fastest, in comparison to eastern white, shortleaf, and Scotch (*Pinus sylvestris* L.) pines. Survival of these two desirable pines was greater than the other pines on plots sprayed for herbaceous vegetation control.

In a 16-year-old mine soil planting in Kentucky, Foster and Henry (1985) reported that loblolly pine performed the best of four pine species planted (Scotch, Virginia, eastern white, and loblolly). The site was a recently-graded contour surface mine that consisted of a level bench area and a steep (40%), outer slope with a southern exposure. Natural reseeding of Virginia pine had occurred throughout most of the study area. Survival of loblolly pine on the level bench was 80%, even though it was most susceptible to cold injury. After 16 growing seasons, average height and diameter of this species was 8.1 m and 19.3 cm, respectively. On the slope site, loblolly pine survival was 40% and height and diameter were 10.8 m and 20.6 cm, respectively. On the bench site, eastern white pine survival was 53% and Virginia pine survival was 55%. Average height of Virginia and eastern white pines on the bench site was 8.2 m and 6.9 m, respectively and average diameter was 10.9 cm and 8.6 cm, respectively. On the slope site, average height of Virginia and eastern white pines was 7.1 m and 3.5 m, respectively.

Average diameter was 10.2 cm and 5.1 cm, respectively for Virginia and eastern white pine. Eastern white pine survival (20%) was very low on the slope site.

Hart and Byrnes (1960) found that survival of hardwoods was generally higher than conifers in a species selection trial in the bituminous coal region of Pennsylvania. Survival of all conifers planted, with the exception of Scotch pine, was less than 50%. Eastern white pine performed poorly. After 10 years, 39% of the planted eastern white pine survived, but they were only 0.9 to 2.4 m tall. The authors suggested that eastern white pine should be planted on sheltered areas of lower slope positions with low incidence of white pine weevil.

In a 30-year-old experimental planting in east-central Ohio, Larson and Vimmerstedt (1983) found that planted red and eastern white pines grew better in pure blocks on surface-mined sites rather than in mixed plantings with hardwoods. Eastern white pine had the best diameter growth of all species on non-calcareous spoil. After 30 years, pines had developed a closed canopy and a deep litter layer.

Loblolly, Virginia, and eastern white pines are highly desirable commercial species in their own right. Researchers have had varied success in planting these three species on mined lands in the Appalachian coal fields. A variety of environmental factors influence the ability of these species to perform well on mined lands. In addition, some requirements of SMCRA have adversely affected the success of tree plantings on mined lands. Certain growth limiting factors can be reduced through the use of cultural treatments, such as fertilization, competition control, and inoculation with mycorrhizal spores. Limited information is available on the response of pines to these treatments since the passage of SMCRA.

Fertilization

Plass (1979) reported that nitrogen (N) deficiencies in mine soils are widely observed, and phosphorous (P) deficiencies commonly occur. Potassium (K) is usually adequate for cover crops, but may be inadequate for certain row and cereal crops.

Bengtson and Mays (1978) subjected one-year-old loblolly pines on a sandstone-derived mine soil in Alabama to a series of N and P fertilization and ground cover treatments. Tree growth and foliage nutrient content were monitored for six years. Treatments included initial N (84 kg/ha) and P (150 kg/ha) fertilization, supplements of N (112 kg/ha) one and/or three years later, or plantings of serecia lespedeza (*Lespedeza cuneata* (Dumont) G. Don) after initial fertilization. After one growing season, a broadcast application of N and P fertilizer increased the growth of established loblolly pine. Foliar analysis confirmed that repeated N applications were needed to maintain the rapid tree growth induced by the initial N and P fertilization on infertile sites. By stand-age six, tree growth rates on the serecia lespedeza plots was nearly equal to plots given two N supplements. The initial P fertilization (150 kg/ha) was considered adequate for the pine overstory for the first rotation on these sites, since retention of fertilizer P and the recycling of organic P would supply adequate P to planted pines. Release of K from weathering spoil was also considered adequate for tree growth. They hypothesized that any K addition might aggravate calcium (Ca) and magnesium (Mg) deficiencies in the plant system.

Fertilization of mine soils may also reduce tree survival, depending on tree species, time of application, fertilizer formulation, and degree of nutrient release (Czapowskyj, 1973). The reduction in tree survival may be due to competition for nutrients, light, and moisture between seedlings and ground cover. Dense herbaceous vegetation growth is often stimulated by broadcast fertilizers, and growth and survival of planted trees is subsequently inhibited on surface-mined lands (Davidson *et al.*, 1984). Slow-release fertilizer pellets are desirable because they are placed near seedling roots to provide nutrients to a tree with minimum stimulation of herbaceous vegetation and can supply a seedling with one to three years of nutrients. Numerous researchers have successfully used slow-release fertilizer pellets in surface-mine plantings to enhance tree survival and growth (Schoenholtz and Burger, 1984; Davidson and Sowa, 1982; Crosse, 1981; Wittwer *et al.*, 1979; Funk and Krause, 1965). Schoenholtz and Burger (1984) found that slow-release fertilizer pellets in combination with chemical weed control generally increased growth of pine seedlings on mined lands in southwestern Virginia for the first two growing seasons. Fertilization response was greater than chemical weed control response at the end of two growing seasons.

On anthracite mine soils in Pennsylvania, eastern white pine, red pine, Japanese larch (*Larix leptolepis* (Sieb. & Zucc.) Gord.), Austrian pine (*Pinus nigra* Arnold), but not white spruce (*Picea glauca* (Moench) Voss), showed a positive response to fertilizer tablets for the four years of this study (Davidson and Sowa, 1982). By the end of four growing seasons, no significant differences in mean average height growth between control and fertilized pines were found. Japanese larch growth was significantly greater than non-fertilized larch for the first two years only. In a companion study, the authors found that growth response to fertilizer tablets starts sooner and lasts longer than granular fertilizers. Davidson and Sowa (1982) noted that fertilizer tablets, when application rates for mine soils are defined and their use is economically justified, have the advantage of being easy to use and do not stimulate herbaceous vegetation competition as do granular fertilizers.

As an alternative to planting, Wittwer *et al.* (1979) successfully seeded northern red oak, chestnut oak, pin oak (*Quercus palustris* Muenchh.), and Virginia pine on

Appalachian surface-mined soils in southeastern Kentucky using fertilizer tablets and bark mulch treatments together. Treatments included 2.5 cm of bark mulch covering seed spots, fertilizer tablets placed adjacent to the seed spot at time of seeding, and a combination of mulch and fertilizer treatments. Mulch and fertilizer treatments together significantly increased tree survival after one year. Fertilizer and mulch treatments each significantly increased tree height. Combined treatments nearly doubled the total height of all species over the single-treatment effect.

In contrast, Cunningham and Wittwer (1984) reported that use of fertilizer pellets used with direct-seeded bur oak (*Quercus marocarpa* Michx.), pin oak, white oak, chestnut oak, and black walnut on mined lands in Kentucky had no significant effect on stocking or height growth. They speculated that soil moisture levels limited the availability of nutrients from these tablets.

The Tennessse Copper Basin, described by Muncy (1986) as a "man-made biological desert" has the low fertility, erosion, low soil moisture, and high surface temperature problems common to areas surface-mined for coal. Berry (1979) found that fertilizer tablets could be used on this site to improve loblolly-pine-seedling growth. Fertilizer tablets (9 and 21 g) and dried sewage sludge (2.15, 0.9, and 0.4% N, P, and K, respectively) tablets (30, 60, and 90 g) placed at the base of planted seedlings increased growth 9- to 20-fold after three years. Survival differences among tablet types were not significantly different. Fertilizer tablets were most convenient to use and most effective in stimulating seedling growth. Berry also noted that planting slit application of fertilizers is less expensive and easier to apply on rugged terrain and less stimulating to competitive vegetation than broadcast application. For revegetation of Copper Basin lands, Muncy (1986) recommended that 21 gram fertilizer tablets be used at time of planting, followed by an aerial broadcast application of fertilizer at the beginning of the third or fourth growing season after the benefits of the fertilizer tablets have been exhausted.

When Berry (1983) used nutrient tablets for spot fertilization of four hardwood species [sweetgum, black alder (*Alnus glutinosa* (L.) Gaertn.), black locust, and sawtooth oak (*Quercus acutissima* Carruthers)] in the same area cited above, 21 gram (20, 4.5, and 4.3% N, P, and K, respectively) fertilizer tablets produced a greater response than 9 gram (20, 3.5, and 1.7% N, P, and K, respectively) tablets or sewage sludge (2, 1, and 0.5% N, P, and K, respectively) tablets. After three years, all hardwoods responded to fertilizer. The concentration of most foliar nutrient elements was unaffected by tablet additions. High foliar concentrations of manganese (Mn), copper (Cu), zinc (Zn), and iron (Fe) in all species were found.

Fertilization of tree plantings on mined lands has had both positive and negative effects on tree growth. Broadcast fertilizers tend to stimulate herbaceous vegetation, creating competition for nutrients, light, and moisture. Fertilizer pellets help alleviate this problem, though lack of available moisture may limit nutrient availability. Inherent site differences will also influence the ability of supplemental fertilizers to stimulate tree growth. By combining fertilizer and ground cover treatments on two different sites, the present study serves to eliminate confounding factors in order to ascertain the factor most limiting growth. The combined effects of fertilizers and ground cover control has been found to greatly increase tree growth. However, little information is available on the ability of these treatments to influence tree growth beyond the first-year establishment period.

Ground Cover Control

Dense, herbaceous cover is established quickly on surface-mined lands to control erosion; however this practice complicates the establishment of tree stands (Kolar, 1985; Davidson *et al.*, 1984; Ringe *et al.*, 1984a; Ashby, 1982; Smith, 1980; Vogel, 1980). Ashby (1982) hypothesized that the compacted cap on the soil due to present reclamation practices (*i.e.*, topsoil replacement) accelerates erosion on reclaimed sites due to increased levels of runoff. In turn, the establishment of pasture species to control erosion leads to competition between trees and pasture species for moisture, thus leading to tree mortality. Kolar (1985) agreed, stating that erosive sites are the result of low infiltration resulting from compaction. On less compacted sites, extremely dense and persistent cover may not be crucial.

Trees respond differently to certain grasses used in reclamation mixes. Several researchers have reported that Kentucky-31 tall fescue (*Festuca arundinaceae* Schreb.) can inhibit establishment of trees and other herbaceous species due to allelopathy (Peters and Zam, 1981; Walters and Gilmore, 1976). However, tall fescue is recommended for reclamation planting by the U.S. Forest Service (Vogel, 1981) and Soil Conservation Service (Ruffner, 1978). Plass (1968) found little effect of tall fescue on eastern white and loblolly pines grown on fescue-covered spoil banks in eastern Kentucky at the end of four growing seasons in comparison to pines grown in no grass cover. Height of white pine was greater on plots without grass, though only significant on one of three plots. Loblolly pine growth was found to be limited by factors other than the fescue cover.

Vogel (1980) studied woody plants in association with herbaceous cover on mined lands using three planting methods: 1) seeding herbaceous cover before tree seeding/planting; 2) seeding herbaceous cover at time of tree seeding/planting; and 3) seeding herbaceous cover after tree seeding/planting. Establishing a dense legume cover at time of tree planting keeps sunlight from the soil surface and thus aids in the development of soil fauna. The legume acts as a substitute for a closed canopy until the tree canopy develops to protect the site. Seeding herbaceous cover at the time of tree planting was favored over seeding before planting and seeding after planting trees.

Establishing herbaceous cover first followed by planting trees often occurs by default. Herbaceous ground cover, required for surface stabilization (after reclamation of post-SMCRA-mined land), is established as soon as practical after reclamation, while trees are only planted in the spring. Sometimes planting crews cannot be contracted until one year later, and in some cases abandoned (mined pre-SMCRA) mined land is being planted to trees. All of these situations result in trees being planted in an existing stand of herbaceous vegetation.

Tackett and Graves (1983) found that topographic aspect and ground cover had a greater long-term effect than fertilization on hardwoods [northern red oak, bur oak, black alder, and paulownia (*Paulownia tomentosa* (Thunb.) Steud.)] direct seeded on mine soils in Kentucky. Direct seeding was used in combination with several treatments on freshly disked spoil. Treatments included mulching, fertilization, ground cover competition, and aspect (ridgetop, northwest, and southeast). Trees seeded alone were 88 cm high after five years compared to a 56 cm average height for those grown in some ground cover. Growth differences were a function of tolerance to competition for light and moisture.

Directly planting woody species in dense herbaceous cover is not generally successful. Chemical weed control may be useful for successful reforestation of surface-mined lands (Torbert *et al.*, 1985; Davidson *et al.*, 1984; Ringe *et al.*, 1984a; Schoenholtz and Burger, 1984; Hensley *et al.*, 1982). Generally, chemical weed control is more economical than mechanical methods that require frequent application (Davidson *et al.*, 1984).

Foresters in the southeastern United States recognize the value of using herbaceous vegetation control in the establishment of pine plantations (Downs and Voth, 1985; Neary, *et al.*, 1985; Bengtson and Smart, 1981). Improved soil moisture and nutrient availability are often cited as reasons for improved growth in pine plantations following herbaceous vegetation control (Neary, *et al.*, 1985). Nelson *et al.* (1981) hypothesized that with a strong response of loblolly pine to early weed control, the opportunity to shorten the rotation two to three years may exist.

Control of herbaceous vegetation on lower Coastal Plain sites of the southeastern United States planted with loblolly pine and slash pine (*Pinus elliottii* var. *elliottii* Engelm.) is important for the full benefits of fertilization to be realized (Neary *et al.*, 1985). Bengtson and Smart (1981) reported an increasing height growth advantage due to weed control treatments (methyl-bromide, simazine, diuron, or hand-weeding) through the first seven years of a slash pine planting in the Florida sandhills. Height growth between treatments stabilized in years eight through ten. The advantage given transplants through the use of herbicides during the first growing season is important for persistent effects, despite re-invasion by weeds. This advantage will then lead to earlier crown closure and development of larger, more vigorous root systems.

Herbicides used in this study were glyphosate and sulfometuron methyl. Glyphosate (as Roundup®) is a pre-planting broad-spectrum foliar-applied herbicide that is labelled for all major forest uses in the Southeast and is effective in controlling herbaceous weeds in young loblolly pine plantations (Voth and Downs, 1985). Glyphosate is readily translocated and accumulates in areas of high metabolic activity. Sulfometuron methyl (as Oust®) is a dispersible granule, pre-emergent herbicide labelled for herbaceous weed control in pine reforestation. In susceptible species, it is absorbed by foliage and roots and translocated through the plant, where it acts as a mitotic inhibitor. Control of susceptible competitors with sulfometuron methyl enhances loblolly pine growth (Gonzalez, 1985).

Ringe *et al.* (1984a) reported that mechanical site scalping was actually damaging to Virginia pine seedlings grown on eastern Kentucky mined lands. Mechanical scalping was compared to eight herbicide treatments. High soil temperature and low moisture content resulted in poorer tree survival and smaller tree height during the first few growing seasons when herbaceous vegetation was scalped to reduce competition than when herbicides were used. The herbicide treatments had a two-fold effect of reducing competition while leaving dead vegetation on the site to serve as a mulch.

Jones *et al.* (1975) recognized the mulching effect of dead vegetation in reporting groundcover and yields on a West Virginia mine spoil using a two-step revegetation system. They recommended that a fast-growing ground cover be established first to minimize erosion, followed by the use of herbicides to kill the cover which then serves as an *in situ* mulch for the establishment of a persistent herbage for pasture or hay. The cost of this *in situ* mulch was one-third to one-eighth as expensive as mulching materials used at time of seeding. This method differs from conventional nurse crops because cereal crops do not need a mulch for establishment as do legumes. Mulch left from chemical weed control does not compete for moisture, serves as an erosion break, and provides a shaded environment.

Chemical weed control may be necessary for one to two years to maintain survival, and for a number of years following establishment to maximize growth (Davidson *et al.*, 1984). Ringe *et al.* (1984a) reported that single-year herbaceous competiton control did not increase survival, but did improve height growth of Virginia pine on mined lands in eastern Kentucky. Hensley *et al.* (1982) reported that eastern white and Scotch pine Christmas trees can be successfully established on mined lands using herbicides.

These studies show the use of pre-planting, non-selective herbicides, such as glyphosate, reduces the competition from existing vegetation in tree planting areas, and application of pre-emergent herbicides aids in maintaining control of competing vegetation.

On mined lands in Kentucky planted with sycamore (*Platanus occidentalis* L.), Virginia pine, and loblolly pine, Vogel (1973) reported that for the first three years herbaceous vegetation covering 70% or more of the ground surface strongly competed with trees planted at the same time as the ground cover. Plots were treated with fertilizer alone, fertilizer and grasses, fertilizer and grasses and legumes, or remained as controls. Fourth- and fifth-year results showed that trees in plots with grass and legume treatments had better height growth than trees in all other treatment plots. This may be due to the fixing of N by legumes.

Schoenholtz and Burger (1984) reported a height response to weed control in two-year-old Virginia, eastern white, and loblolly pine seedlings growing on mined lands in southwestern Virginia. After three growing seasons, a tree species trial in the same region showed that growth of trees in plots sprayed with herbicides for herbaceous vegetation control were no greater than non-sprayed plots for loblolly or Virginia pines, but survival of these species increased (Torbert *et al.*, 1985).

It has been shown that pines can be successfully established on mined lands in southwestern Virginia. The use of herbicides to establish tree plantings on mined lands has also been successful. Of interest in this current study is the longer-term effect of previously-applied herbicides on tree performance and how mine soil properties may be affected by this treatment.

Cultural Treatment Interactions

Neary *et al.* (1985) maintain that the full benefits of fertilizing loblolly and slash pines on some lower Coastal Plain flatwood Spodosols of the southeastern United States cannot be realized unless competing vegetation is controlled. The combination of fertilizer and chemical weed control improves pine growth in both commercial plantations and on surface-mined lands (Barnett and Tiarks, 1987; Neary *et al.*, 1985; Schoenholtz and Burger, 1984; Bengtson and Smart, 1981). The effect of these treatment combinations over time on surface-mined lands has not been extensively evaluated. Due to the requirement for the establishment of a dense ground cover by SMCRA, knowledge of the interactions of these treatments on pine performance and mine soil properties is needed. The success of combined fertilization and ground-cover control treatments on pre-SMCRA flat benches is also of interest as more lands mined prior to application of SMCRA are being reclaimed.

Mine Soil Genesis

As spoil from the surface-mining of coal weathers, pedogenic processes form mine soils from the unconsolidated material. Mine soil is defined as blasted overburden material (mine spoil) placed on a final reclaimed surface and exposed to the soil forming factors of climate, vegetation, and time (Daniels and Amos, 1984). As mine soils age, pedogenesis occurs. The ability of mine soils to supply nutrients and support plant growth is constantly changing.

Stevens and Walker (1970) reported that trends in chronosequences and soil formation show that rapid initial changes are due mainly to organic matter accretion. The initial course of soil development is correlated with vegetation. In turn, vegetation is affected by external and ecological factors, such as light, nutrients, and water. Thus, in terms of mine soil formation, one has the opportunity to manage or alter soil development through the selection of the vegetation during the reclamation process (Schafer, 1984).

Sweeney (1979) studied two-, five-, and ten-year-old mine soils from three parent material types (sandstone, shale, and mixed) from southern West Virginia to determine if pedogenesis could be observed in a 10-year period. He found that 10-year-old soils had more organic matter than the two- and five-year-old soils. However, five-year-old soils were most fertile, with two- and 10-year-old soils having approximately the same fertility. Weathering and release of bases from rock fragments, which are depleted by the time the soil is 10-year-old may explain these results. In a greenhouse experiment, Everett (1981) found that biological weathering of mine spoil under a serecia lespedeza and black locust cover influenced P and K availability in mine soils from Buchanan County, Virginia. Phosphorous became less available as apatite became more soluble and P was bound by Fe. Potassium was supplied by mica weathering.

In a simulated physical and chemical weathering experiment using mine spoil from the Wise Formation in Buchanan County, Virginia, Howard (1979) found no measurable pedogenic activity after two years of weathering. He observed physical disintegration of rock fragments and weak development of structure in the surface layers of two-year-old spoil. Daniels and Amos (1984) found that distinct, well-aggregated A horizons form in several years after revegetation of topsoil substitutes in southwestern Virginia. Levels of exchangeable calcium (Ca) and magnesium (Mg) increased for several years and then decreased as dissolution of carbonates slowed. As micas weathered to vermiculite, exchangeable K increased. Over time, P availability was expected to be limited by fixation by Fe-oxides. In turn, N fixation by legumes may be limited if their requirement for P is not satisfied. Siltstone spoils were higher in Fe-oxides, P-fixing potential, and soluble salts than sandstone spoils.

In a study on chemical properties and particle size distribution of mine spoils in West Virginia, Plass and Vogel (1973) reported that spoils had a pH of 5.0 or higher and an average of 37% soil size material (< 2 mm) by weight. The spoils were found to be deficient in N and P. The authors suggested that systematic placement of overburden could result in more productive soils.

In an 18-year-old tree and shrub planting established on a mine soil in Kentucky, Wade et al. (1985a) found that pH increased, while soluble salts and available P decreased during this 18 year period. The change in pH was species specifiic. Mine soil pH under Austrian pine was significantly lower than the mine soil under mimosa (*Albizzia julibrissin* Durazz.), birch (*Betula* spp.), or olive (*Eleagnus* spp.) plantings. Levels of available P and salts in mine soils were not different among species.

Foster and Henry (1985) found that after 16 year, Ca, Mg, and P increased and pH remained the same on mine soils under 31 woody species grown on a contour site in Kentucky. Organic matter and soil development increased over time. The improvement in site quality was due to the fall and decomposition of litter from the various tree species on the site.

A pine (loblolly, Virginia, and pitch) and hardwood (yellow-poplar (*Liriodendron tulipifera* L.), northern red oak, American sycamore, red maple, white oak, and black oak (*Quercus velutina* Lam.)) plantation established in 1965 on a Kentucky mine soil was evaluated after 20 year and site indices were calculated from height-age data and site index curves of Hampf (Wade *et al.*, 1985b). In general, soil pH on these sites increased over time, while specific conductivity decreased due to the ameliorating effects of time and vegetation. Phosphorous also decreased in these soils. Time and vegetation were found to have significant influences on soil development. After weathering for a 10-year period, B horizons were present at a depth of 1 to 1.8 m. Soil depth was greater in most plantings than on adjacent unmined areas. Spoil weathered to similarly-textured (clay loam) soils as found on the adjacent unmined areas. Average site index at two sites for loblolly pine at base age 50 was 28.3 m. Site index for Virginia pine was 27.3 m. The authors claim productivity at optimum rotation period may be less than site indices indicated because 1) they are based on a base age of 50 while the stand is only 20-years-old; and 2) the site index curves used were developed for stands grown on natural soils.

Mine Soil and Cultural Treatment Interactions

Reforestation cultural treatments can influence mine soil properties. Safaya and Wali (1979) reported that fertilizer treatment had little effect on spoil properties (pH, electrical conductivity, saturation potential, and major cations of various saturation extracts) in North Dakota mine soils amended with fertilizer, gypsum, leonardite (oxidized lignite), and H_2SO_4. The other treatments (gypsum, leonardite, and H_2SO_4) did influence spoil properties. Gypsum, leonardite, and H_2SO_4 all lowered pH. Electrical conductivity was higher under the gypsum and H_2SO_4 treatments. Leonardite decreased the water saturation potential. Gypsum and H_2SO_4 both increased the amounts of exchangeable cations.

Wilson (1957) found that vegetated mine soils were better aggregated than non-vegetated mine soils in West Virginia. Ten-year-old non-vegetated coal land spoil was slightly aggregated, and vegetated spoil was better aggregated. He observed that forage grasses and legumes were better than black locust, which in turn was better than pine for aggregating mine soil due to biological effects of vegetation.

In Colorado, McGinnies and Nicholas (1980) found that N fertilization increased above- and below-ground growth of wheatgrass on topsoil and mine spoil in the greenhouse. They suggested that increased herbage and root growth caused by N fertilization could be an aid in soil development and stabilization, especially on reclaimed slopes with shallow topsoil.

On an Indiana surface-mined site, Reinsvold and Pope (1985) planted black locust and black alder to ameliorate the site. Chemical soil properties to a surface depth of 30 cm were determined. Plots were either fertilized with 50 kg/ha each of P and K or left as controls. After two growing seasons, organic matter increased from 0.31 to 0.46% for non-fertilized and fertilized plots, respectively. Total soil N was 53 and 83 kg/ha greater on non-fertilized and fertilized plots, respectively, in comparison to before-planting values. Fertilizers increased available P and K in the soil and indirectly affected soil and foliar N concentration. Soil acidity, Ca, Mg, and sodium (Na) were not affected by fertilization. Increased levels of total N, nitrate (NO_3^-), and soil organic matter were due to stimulation of the dinitrogen fixation rate of black locust and black alder by fertilization.

Byrnes *et al.* (1985) assessed changes in surface properties of mine soils in southwestern Indiana. The area was vegetated in hardwoods and a grass-legume ground cover. Soil properties were measured before and 4 year after revegetation. Bulk density decreased, and total and non-capillary porosity in the topsoil increased. A decrease in electrical conductivity was found in the C1 and C2 layers. Soils in plots receiving chemical weed control treatments showed no influence of this treatment on P, K, Mg, Ca, or Na levels. There was little influence of this treatment on physical soil properties.

Higher capillary porosity and root biomass was found in the surface horizon of non-treated soil.

Though individual treatment effects on the relationship between cultural treatments and mine soil development have been reported, information on the interaction of cultural treatments, specifically fertilization and ground-cover control, on mine soil surface properties is lacking.

Fertilizer and Ground Cover Effects on Mine Soils and Pine Growth

Introduction

The commercial surface-mining of coal in the United States is a practice that is more than a century old (Curtis, 1978) and revegetation of mined lands has been practiced since the early part of this century. Research on the reforestation of mined lands was begun by the United States Forest Service in 1937 (Curtis, 1978) and since then, many researchers have provided information on the success of long-term plantings of woody species on surface-mined lands and on the potential of mine soils to yield wood products (Plass, 1979; Plass and Burton, 1967).

The Surface Mining Control and Reclamation Act of 1977 (SMCRA) set nationwide standards for the commercial mining of coal and the reclamation of mined lands. This law recognizes forestry as a post-mining land use. To ensure adequate revegetation of mined sites, SMCRA requires that a site maintain 90% vegetative cover for at least five years after the last reclamation treatment. A monetary bond is set and the mining company gets this bond money released after the five-year period is over and reclamation requirements are met. Therefore, when forestland is designated as the post-mining land use, the success of the final stage of reclamation is a function of the status of the reforestation effort at the end of this five-year period. Aspects of SMCRA that affect the success of reforestation of mined lands include back-filling and grading, topsoil recovery, revegetation, and land use (Wolf, 1983). Areas contour-mined before application of SMCRA generated a highwall-bench-outslope topography after mining. Surface mine operators are now required to backfill, compact, (where advisable to insure stability or to prevent leaching of toxic materials), and grade in order to restore the approximate original contour of the land with all highwalls, spoil piles, and depressions eliminated (PL 95-87 Sec. 515 (b) (3)). In the Appalachian coalfields, this requirement recreates steep slopes with limited post-mining land uses (Daniels and Amos, 1984). Forestry is favored because of the inaccessiblity of these sites to farm machinery and their unsuitability for building. Forests have the added advantage of remaining intact for long periods and, in the process, creating a litter layer to protect a site from erosion after the herbaceous erosion control cover dies out. In the state of Virginia during the last three years, approximately 80% of the mining permit requests listed forestry as the post-mining land use.

The requirement for the establishment of dense ground cover on reclaimed sites is one of the major obstacles faced when forestry is the post-mining land use (Kolar, 1985; Davidson *et al.*, 1984; Ashby, 1982). This ground cover is established to stabilize and protect mined areas from erosion and air and water pollution (Wolf, 1983). However, dense ground cover competes with tree seedlings for light, moisture, and nutrients (Davidson *et al.*, 1984). Vegetation management of some form is crucial to tree stand establishment on mined sites. Non-chemical methods of ground-cover control can disturb the site, are of limited duration, and can cause tree mortality due to high surface temperatures on bare sites (Ringe *et al.*, 1984a). Herbicides can be used to control herbaceous competition without damaging the site. Downed vegetation can then serve as an *in situ* mulch to protect the site from erosion (Ringe *et al.*, 1984b; Jones *et al.*, 1975).

Foresters in the southern pine region have successfully used herbicides for herbaceous vegetation control on an operational basis in establishing loblolly pine plantations (Fitzgerald, 1982), and many researchers have shown positive influences of herbicides on first year survival and growth of tree plantings on mined lands (Carpenter and Albers, 1985; Ringe *et al.*, 1984a; Schoenholtz and Burger, 1984; Philo *et al.*, 1983; Hensley *et al.*, 1982). However, little is known of the carry-through effects of ground-cover control on tree plantings. This study serves as a means of examining effects beyond first-year establishment.

Mine soils are characteristically low in plant available nutrients. During the mining process, plant available nitrogen (N) and phosphorous (P) in the original surface layers are often removed or buried beneath the replaced overburden. Fertilization with N and P, as well as other nutrients, is important in ensuring the success of revegetation efforts on mined sites. The use of broadcast fertilizers during reforestation, however, aggravates the problem of herbaceous competition. A viable alternative is the use of slow-release fertilizer pellets, placed at the base of the tree in the planting slit. These pellets will provide the seedling with one to three years of nutrients with minimal stimulation of herbaceous vegetation. Fertilizer pellets have been found to increase survival and growth of tree seedlings on mined lands (Schoenholtz and Burger, 1984; Davidson and Sowa, 1982; Crosse, 1981; Wittwer *et al.*, 1979). Muncy (1986) reported the effectiveness of a combination of slow-release fertilizer pellets at time of tree planting and subsequent broadcast fertilization at the beginning of the third or fourth growing season in the reforestation of Copper Basin lands in Tennessee.

Limited information on the combined effects of fertilization and ground-cover control treatments on the growth of commercially important pine species during a full five-year bond period is available. Accordingly, the purposes of this study were 1) to examine the effects of fertilization and ground-cover control on loblolly, Virginia, and eastern white pines grown on surface-mined lands through a five-year period; and 2) to examine relationships among pine growth, cultural treatments, and mine soil properties, in order to better understand the factors that influence pine productivity on reclaimed sites.

Materials and Methods

Study Site Description and Characterization

The study sites were located in Wise Co., Virginia which is in the southern part of the Appalachian coal region. The topography is divided by degree of dissection, comprised of: deeply dissected and steep (> 50% slope); less deeply dissected and steep (2-20% slope); and rolling ridgeland plateaus. The mine spoil in this area is derived from the Pennsylvanian age Pottsville series. The portion of the Wise formation exposed consists of about 70% sandstone, 20% siltstone, and 10% shale, mudstone, and coal. The dominant Fe-oxide is geothite and muscovite is the dominant mica in the rocks. The carbonates are a complex mixture of species or complex (Fe, Mn, Ca, Mg, Zn) phosphatic carbonates or apatites (Howard, 1979). Native forests in the region are a mixture of hardwoods, among which are yellow-poplar (*Liriodendron tulipifera* L.), oaks (*Quercus spp.*), and ash (*Fraxinus spp.*). Scarlet (*Q. coccinea* Muenchh.) and chestnut (*Q. prinus* L.) oak are the most abundant oaks. Natural forest soils are predominantly of the Muskingum and Weikert series. Muskingum soils (Typic Dystrochrepts) are shallow infertile soils, weathered from noncalcareous sandstones. Weikert soils (Lithic Dystrochrepts) are associated with Muskingum soils and are weathered from noncalcareous shales (SCS, 1954). Wise County has a warm-temperate continental climate, characterized by cool summers and moderately cold winters. Average annual temperatures and precipitation during the term of the study were 12.0°C and 107.4 cm, respectively (Table 1).

Table 1. Climatological data for Wise Co., VA 1981-1985.

Year†	Avg. Temp.‡ (°C)	Avg. Ppt.§ (cm)	First Frost¶ (mo/day)	Last Frost# (mo/day)	Growing Season†† (days)
1981	11.3	114.9	10/03	5/13	165
1982	12.6	127.8	10/17	4/23	177
1983	12.0	103.4	11/04	5/09	179
1984	11.9	98.2	11/03	4/20	197
1985	12.2	93.3	11/08	4/10	212

† Climatological Data - Virginia Vols. 91-96.
National Oceanic and Atmospheric Administration
National Climatic Data Center, Asheville, NC.
‡ Avg. Temp. = average yearly temperature
§ Avg. Ppt. = average yearly precipitation
¶ First fall minimum of 0°C or below.
# Last spring minimum of 0°C or below.
†† Number of days between first and last frost.

Two sites within this region were chosen for this study: a site returned to approximate original contour (AOC) (Site I) and a flat bench site (Site II) (Figure 1). Site I is located 8 km west of Norton, VA at an elevation range of 580 to 610 m. Average slope is 38% with a west-facing aspect. The site is located at 82° 43′W longitude and 36° 55′N latitude. Site I is characteristic of the condition of surface-mined lands after the passage of SMCRA. The area was mined and returned to contour in 1979. The site was hydroseeded in 1980 with a mixture of Kentucky-31 fescue (*Festuca arundinacea* Schreb.), red top (*Agrostis alba* L.), ladino clover (*Trifolium repens ladino* L.), annual rye (*Lolium multiflorum* Lam), and serecia lespedeza (*Lespedeza cuneata* (Dumont) G. Don) in combination with 56 kg/ha N, 49 kg/ha P, and 93 kg/ha K (560 kg/ha of 10-20-20 fertilizer) and 1681 kg/ha of wood fiber mulch (Schoenholtz, 1983). The mine soil at this site is predominantly derived from siltstone overburden (Schoenholtz and Burger, 1984).

The second site (Site II) is located 13 km east of Norton, VA at an elevation range of 790 to 825 m, and has approximately <2% slope. It is located at 82° 42′ W longitude and 37° 01′ N latitude. Site II is characteristic of the condition of lands mined prior to the application of SMCRA. A total of 18 study plots were equally assigned to adjacent benches of similar age and site conditions (Figure 1). One bench was mined in 1977 and hydroseeded in 1978. The other bench was mined in 1978 and hydroseeded in 1979. On both benches, the hydroseed mix consisted of a combination of Kentucky-31 fescue red clover (*Trifolium pratense* L.), ladino clover, annual rye, red top (*Agrostis alba* L.), and serecia lespedeza. Included in the mixture was 65 kg/ha N, 48 kg/ha P, and 47 kg/ha K (409 kg/ha of 16-27-14 fertilizer) and 9354 liters/ha of Conweb® mulch (Schoenholtz, 1983). The mine soil is predominantly derived from sandstone overburden (Schoenholtz and Burger, 1984). After the fifth year of this study, Site I was covered primarily by serecia lespedeza and Kentucky-31 tall fescue, while the herbaceous cover on Site II was predominantly serecia lespedeza.

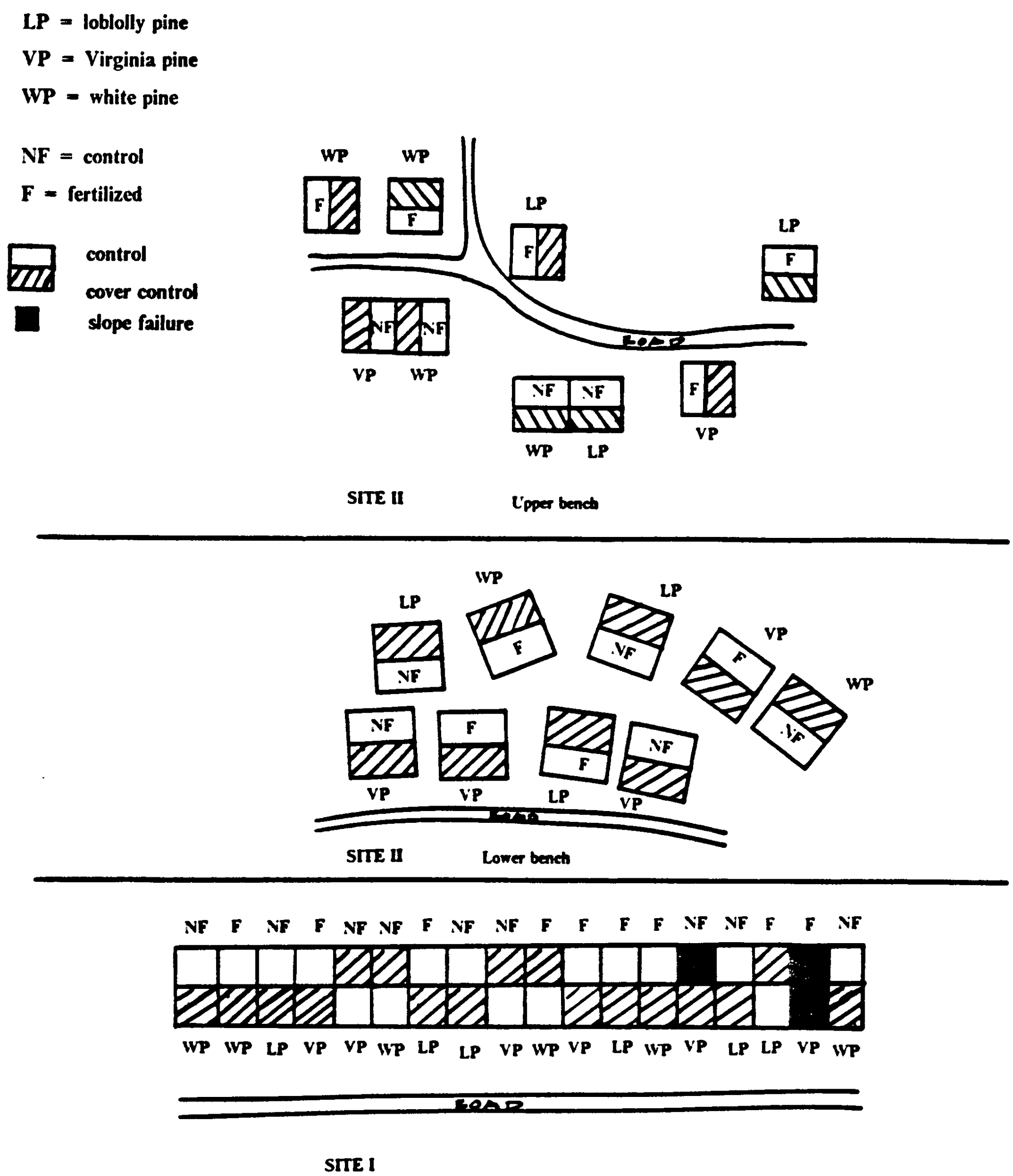

Figure 1. Field study site layout.

Soils of the two sites were initially characterized by Schoenholtz (1983). Composite samples made up of subsamples (surface 20 cm) taken from across the study sites were analyzed for bulk density, particle size, pH, organic matter, total N, extractable P, and exchangeable cations (Ca, K, Mg) (Table 5). Mine soil properties re-analyzed after five years included particle size, pH, soluble salts, organic matter, total N, mineralizable N, extractable P, and exchangeable cations (Ca, K, Mg).

Tree Species Description

Three commercially-important pines were chosen for this study: loblolly, Virginia, and eastern white pines. Loblolly pine is not native to the mountains of southwestern Virginia, yet it has been successfully planted north of its natural range (Vogel, 1981; Ruffner, 1978). It is the most widely planted species in the world and is desired for its fast growth and ability to perform well on a variety of sites. Vigorous seedlings of loblolly pine make several surges of growth (normally three) during the growing season (Fowells, 1965). Loblolly pine provides aesthetic value and screening, and wildlife cover and food (Vogel, 1981), in addition to its primary use as pulpwood and lumber.

Virginia pine is native to the mountains as well as most of the rest of Virginia. It is the most widely planted conifer on mine soils, especially in the Appalachian region. Virginia pine is adapted to a range of mine soils, performs well on acid and droughty soils, and is a pioneer species on mine soils within its range (Vogel, 1981).

Eastern white pine is also native to southwestern Virginia. White pine seedlings are easily suppressed by competition and grow slowly for the first three years. However, between the ages of 10 to 20, its height growth can average one meter or more per year

(Fowells, 1965). After its initial period of slow growth, white pine stands can grow faster, sustain rapid growth over a longer period, and yield more volume per hectare than stands of hardwood species (Landcaster and Leak, 1978). Eastern white pine is a widely desirable timber species that grows best on moderately acid mine soils (Vogel, 1981).

Study Design

At both sites, each of the three pine species (loblolly, Virginia, and eastern white) was randomly assigned to six plots. To evaluate the effect of cultural treatments on the growth of each species, a completely randomized split-split plot design was used to determine the effects of fertilization, ground-cover control, and artificial mycorrhizal inoculation.

Three of the six plots used for each site-species combination were randomly selected and fertilized (main plot factor, control versus fertilized). The ground-cover control treatment (sub-plot factor, control versus herbicided) was applied to all plots by splitting them and randomly selecting a sub-plot to be sprayed with herbicides. Inoculated seedlings (sub-sub-plots, non-inoculated versus inoculated seedlings) were planted in half the row within each sub-plot. Three replicates of each treatment combination, fertilization, ground-cover control, and inoculation, were installed at each site for each species.

Due to dense vegetation on the bench site, the entire site was harrowed in February and again in April 1981. By June, 1981 the planting beds on both sites were similar. All plots (17.5 m × 20.0 m) were planted with 136 16-week-old loblolly, Virginia, or eastern white pine containerized seedlings in June 1981. Seedlings were planted on a 2.25 m (between rows) by 2.5 m (within row) spacing. A row of buffer trees separated the ground-cover control treatments (Figure 2). In addition, plot border trees were designated buffer trees. This left 72 measurement trees per whole plot or 18 trees per sub-sub plot.

Seedlings receiving fertilization were planted with an Agriform® 21 g slow-release fertilizer pellet (20-10-15) placed 10 cm deep within 10 to 15 cm of the seedling (placed in the dibble closing hole) (Table 2). In April 1984, prior to the fourth growing season, 56 kg N/ha as NH_4NO_3 were broadcast-applied to these plots. This supplemental N fertilization would violate bond requirements, but N was applied to determine if N continued to limit pine growth beyond age one or if other N-sources such as N-fixing serecia lespedeza and atmospheric N provide adequate N.

Ground-cover control was accomplished by broadcast spraying glyphosate (as Roundup®) prior to planting in June 1981 at a rate of 0.62 kg active ingredient (a.i.)/ha. Seedlings were kept free of overtopping vegetation by re-applying glyphosate at the same rate in August 1981. In May 1983, sulfometuron methyl (as Oust®) was applied in half meter bands on either side of the tree at the rate of 0.22 kg a.i./ha to continue ground-cover control on these plots through the third growing season.

Artificial inoculation was accomplished by planting inoculated and non-inoculated seeedlings in alternate rows within the whole plot. Emerging seedlings were inoculated in the greenhouse with *Pisolithus tinctorous* (Pers.)(Coker and Couch (Pt) (Schoenholtz, 1983).

Field and Laboratory Procedures

Initially, there were 72 test trees per whole plot. Twelve of these test trees were destructively sampled in the initial study. For the present study, a maximum of 60 test

X*	O*	X*	O*	X*	O*	X*	O*
X*	O*	X*	O*	X*	O*	X*	O*
X*	O	X	O	X	O	X	O*
X*	D	D	D	D	D	D	O*
X*	O	X	O	X	O	X	O*
X*	O	X	O	X	O	X	O*
X*	O	X	O	X	O	X	O*
X*	O	X	O	X	O	X	O*
X*	O*	X*	O*	X*	O*	X*	O*
X*	O	X	O	X	O	X	O*
X*	O	X	O	X	O	X	O*
X*	O	X	O	X	O	X	O*
X*	O	X	O	X	O	X	O*
X*	D	D	D	D	D	D	O*
X*	O	X	O	X	O	X	O*
X*	O*	X*	O*	X*	O*	X*	O*
X*	O*	X*	O*	X*	O*	X*	O*

X = Inoculated seedling
O = Non-inoculated seedling
D = Destructively sampled seedling
* = Buffer seedling

Figure 2. Split-split plot design.

Table 2. Agriform® fertilizer tablets - guaranteed analysis

Ingredient†	Percentage
Total Nitrogen (N) - 7% water soluble N 13% water insoluble N	20.0
Available Phosphoric Acid (P_2O_5)	10.0
Soluble Potash (K_2O)	5.0
Calcium (Ca)	2.6
Sulfur (S)	1.6
Iron (Fe)	0.35

† Derived from ureaformaldehyde, calcium phosphate, potassium sulfate, calcium sulfate, and ferrous sulfate. Potential basicity: 5% or 45.4 kg calcium carbonate equivalent per ton.

trees remained per whole plot. All trees that would be defoliated if foliage were collected were not counted as surviving. Due to slope failure at Site I, plot two and the control half of plot five were lost from the study prior to the third growing season (Figure 1).

In March 1984 and 1986, surviving trees were counted and their height and root collar diameter were measured. $Diameter^2 \times height$ was calculated for each tree and used as an index of tree volume. Foliage from each test tree was collected, and combined into a composite sample for each sub-plot.

Foliage was oven-dried at 65 °C, ground, sieved through a 20 mesh screen, and analyzed for foliar nutrient concentration. Nutrient analysis tests were run on both third- (1984) and fifth- (1986) year foliage samples in a manner similar to the techniques used by Schoenholtz (1983). Foliar phosphorous (P), potassium (K), calcium (Ca), and magnesium (Mg) concentrations in dry-ashed (500 °C) subsamples extracted with 1.2 M HCl (Jones and Steyn, 1973) were analyzed using a Jarrel-Ash inductively coupled argon plasma (ICAP) spectrophotometer. Foliar nitrogen (N) concentration in microKjeldahl acid digests (Bremner and Mulvaney, 1982) were colorimetrically analyzed on a Technicon® Autoanalyzer II via the ammonia-salicylate complex (Technicon, 1978).

Mine soils were sampled in April 1984 (after the third growing season) from each cover control split-plot. Two push tube cores were taken within and between tree rows for a composite of 32 subsamples per split-plot. Soil samples were dried at room temperature, ground, and sieved through a 2 mm sieve; coarse fragments were discarded. Soil chemical and physical properties were determined by the the methods used by Schoenholtz (1983). Hydrogen ion activity was measured with a combination electrode in a 1:2 soil:water mixture (McLean, 1982). Exchangeable soil cations (K, Ca, Mg, Mn) were extracted with 1 M ammonium acetate (NH_4OAc) adjusted to pH 7 (Thomas, 1982) and analyzed by ICAP spectroscopy. Phosphorous was extracted with sodium bicarbonate adjusted to pH 8.5 (Olsen and Sommers, 1982) and determined colorimetrically using the ascorbic acid method of Watanabe and Olsen (1965). Total soluble salts were estimated on a Markson conductivity meter using a 0.001 M KCl standard solution (Rhoades, 1982). Total nitrogen was determined by standard Kjeldahl digestion and analysis with a Technicon® Autoanalyzer II (Bremner and Mulvaney, 1982) via the ammonium - salicylate complex (Technicon, 1978). Organic matter was determined by the Walkley-Black chromic acid oxidation procedure (Nelson and Sommers, 1982). An available nitrogen index was determined by a modified seven-day anaerobic incubation procedure described by Waring and Bremner (Keeney, 1982). Soils were extracted with 3M KCl in a 10:1 ratio of soil to KCl. Filtrate was analyzed for NH_4-N (as mineralizable N) on a Technicon® Autoanalyzer II (Technicon, 1973). Particle size distribution (<2mm fraction) was determined on six randomly selected sub-plot samples at each site using the modified Bouyucous hydrometer method (Day, 1965).

Statistical Analysis

Data were analyzed individually for each site and species combination using the Statistical Analysis System (SAS, 1982). For third- and fifth- year data, analysis of variance procedures were used to evaluate treatment effects on tree volume-index, height, root-collar diameter, and foliage nutrient concentrations for each species on each site (Table 3). Fifth-year survival data were analyzed after arcsine transformation of the percentages. Inoculation treatment effects at age five were evaluated only for survival, volume index, height, and diameter responses (Table 4). Analysis of variance was also used to evaluate treatment effects on soil properties at each site (Table 3). All cultural treatments were fixed effects. When interactions occurred among treatments, a one-way analysis of variance was used to interpret combined treatment effects on tree, foliage, and soil response. Duncan's multiple range test was used to compare differences among three or more means.

Relative volume-index responses (as a percentage) to the main fertilizer and ground-cover control treatments and treatment interaction were calculated for stand-ages one, two, three, and five. The volume-index of the control was subtracted from each fertilizer and ground-cover control treatment replication. This value was then divided by the same control volume-index. For main effect response, the average volume-index of non-fertilized and non-herbicided plots were used as treatment control values. For analysis of the interaction response, the average volume-index of the non-treated trees (no fertilization or ground-cover control) was used as the control value. Relative volume-index response was plotted against stand age and points were connected by a straight line to give a conservative estimate of tree response to treatments through the five-year period.

The relationship between the volume-index and soil properties and foliar nutrients were also plotted. Transformations were made if warranted, and the best fitting linear relationship was determined.

Table 3. ANOVA table for testing cultural treatment effects on foliar and soil nutrients and third-year pine performance.

Treatment Factor	Degrees of Freedom
Main plot:	
Fertilization (F)	1
F × Rep (Ea)	4
Split plot:	
Ground Cover (GC)	1
F × GC	1
F × GC × Rep (Eb)	4
TOTAL:	11

Table 4. **ANOVA table for testing fertilizer, ground cover, and inoculation effects on fifth-year pine performance.**

Treatment Factor	Degrees of Freedom
Main plot:	
Fertilization (F)	1
F × Rep (Ea)	4
Split plot:	
Ground Cover (GC)	1
F × GC	1
F × GC × Rep (Eb)	4
Split-split plot:	
Inoculation (I)	1
F × I	1
WC × I	1
F × GC × I	1
F × GC × I × Rep (Ec)	8
TOTAL:	24

Results and Discussion

Fertilization and Ground Cover Effects on Mine Soil Properties

The mine soil properties of the two sites were notably different (Table 5). When the study was initiated, Site I had higher levels of exchangeable K and Mg, and $NaHCO_3$- extractable P. The amount of silt and clay in the fine fraction (< 2mm) was also higher at on Site I. On Site II, the older of the two sites, percent sand, pH, and organic matter levels were higher. Site and mine soil differences are due to differences in overburden material, predominantly siltstone material on Site I and sandstone material on Site II; the age of the mine soil; and the percent slope and aspect of the site.

Soil properties changed with time on both sites. Organic matter and total N levels increased, while pH and $NaHCO_3$-extractable P decreased from time of planting to the end of the five-year period (Table 5). Similar trends in mine soil properties with time have been reported for this region (Daniels *et al.*, 1986; Roberts, 1986; Daniels and Amos, 1984; Sweeney, 1979). In general, aging of the mine soils over the five-year period has made them more desirable for tree growth. Reduced levels of exchangeable cations suggest lower soluble salt levels, as evidenced by lower soluble salt levels between third- and fifth-year soils (Table 5); higher OM and total N levels suggest higher amounts of mineralizable N; and a pH range between 4.5 and 5.5 is best for these pine species. However, lower levels of extractable P suggested a possible P deficiency due to fixation by the large amounts of Fe-oxides present in mine soils of the region (Daniels and Amos, 1984; Everett, 1981).

Table 5. Mine soil and site characteristics of two surface-mined sites in southwestern VA.

Soil property†	SITE I Year 0§	SITE I Year 3	SITE I Year 5	SITE II Year 0§	SITE II Year 3	SITE II Year 5
Slope	38 ± 1.5			<2		
Particle size						
Coarse fragments (%)	49 ± 1.5	NA	NA	43 ± 1.5	NA	NA
Sand (%)	12 ± 0.5	26 ± 1.4	32 ± 0.9	18 ± 1.1	50 ± 2.4	52 ± 2.9
Silt (%)	21 ± 0.7	42 ± 1.2	39 ± 0.8	16 ± 0.7	29 ± 1.2	29 ± 2.1
Clay (%)	18 ± 0.6	32 ± 0.6	29 ± 0.7	12 ± 0.6	20 ± 1.9	19 ± 1.8
Biomass (kg/ha)	3811±197	NA	NA	NA	3878±475	
Bulk density (g/cc)	1.3 ± 0.06	NA	NA	NA	1.4 ± 0.04	
Organic matter (%)	1.20 ± 0.06	1.54 ± 0.10	1.66 ± 0.10	1.80 ± 0.16	1.69 ± 0.12	2.04 ± 0.13
pH	5.4 ± 0.14	4.6 ± 0.08	4.7 ± 0.08	6.1 ± 0.14	5.0 ± 0.10	5.0 ± 0.07
Soluble salts (mg/kg)	NA	244 ± 14	163 ± 7	NA	225 ± 8	132 ± 8
Total N (g/kg)	1.02 ± 0.034	0.94 ± 0.003	1.02 ± 0.003	1.08 ± 0.061	0.81 ± 0.040	1.08 ± 0.014
Mineralizable N (mg/kg)	NA	4.15 ± 0.8	7.98 ± 0.8	NA	7.35 ± 1.5	17.40 ± 2.8
Extractable P (mg/kg)	7.43 ± 0.31	4.52 ± 0.18	4.55 ± 0.15	6.19 ± 0.31	3.07 ± 0.17	3.00 ± 0.13
Exchangeable cations						
K (mg/kg)	101 ± 3.5	104 ± 2.4	106 ± 1.7	80 ± 2.7	60 ± 1.5	69 ± 2.1
Ca (mg/kg)	610 ± 38	593 ± 26	603 ± 27	576 ± 49	536 ± 25	543 ± 26
Mg (mg/kg)	431 ± 13	357 ± 9	354 ± 7	349 ± 13	220 ± 6	216 ± 7
Mn (mg/kg)	NA	32 ± 1.5	23 ± 0.9	NA	31 ± 2.3	26 ± 1.4

† Values are means (standard errors) of measurements at each site at the end of three and five growing seasons, based on the fine fraction (<2mm) only.
§ Values from Schoenholtz and Burger, 1984
NA = not available

By the end of the five-year period, total N in fertilized plots was higher in Site I, with a similar trend occurring on Site II (Table 6). Soil organic matter levels were higher on herbicided plots on Site II with a similar trend present on Site I. Fertilized plots and non-fertilized, herbicided plots on Site I had less mineralizable N in the mine soil than control plots (no fertilization or ground-cover control) (Figure 3).

Both fertilizer and ground-cover control treatments stimulate microbial activity through a priming effect and increase the rate of litter decomposition and N mineralization. Accelerated decomposition speeds N cycling in soil/plant systems (Gosz, 1984). Although foliar N concentrations were lower in pines on treated plots (Figure 6), N content, or total accumulated N in tree biomass, was much larger in these plots due to the larger tree size. This is a common phenomenon; treatments or conditions that stimulate N cycling in forest systems usually result in greater productivity and larger portions of the reactive, organically-combined N contained in live biomass (Olson, 1963).

On Site I, higher levels of available P ($NaHCO_3$-extract) (4.8 versus 4.3 mg kg^{-1}) (Table 6) were extracted from the mine soil in herbicided plots. Available K (exchangeable) was also lower in herbicided plots on both sites (109 versus 104 mg kg^{-1} and 73 versus 66 mg kg^{-1} on Site I and II, respectively). These slightly lower values on herbicided plots, like mineralizable N, were probably the result of greater uptake by the tree crop over the five-year period.

The combined effects of these cultural treatments on mine soil properties are subtle and indirectly imposed through the differential response of the ground cover and the tree crop to the treatments. These differences demonstrate the complex dynamic interrelationships between the vegetation, mine soils, and cultural treatments.

Table 6. Cultural treatment effects on fifth-year mine soil properties of two surface-mined sites in southwestern VA.

SITE I

Treatment	N	OM	Mineralizable N	Soluble Salts	pH
	(g kg^{-1})		(mg kg^{-1})		
Fertilization					
Control	0.98 a†	17 a	9.9 §	169 a	4.5 a
Fertilized	1.06 b	16 a	5.8	156 a	5.0 a
Ground Cover					
Control	1.05 a	18 a	9.3 §	159 a	4.7 a
Herbicided	0.99 a	16 a	6.8	168 a	4.7 a

Treatment	P	K	Ca	Mg	Mn
	(mg kg^{-1})				
Fertilization					
Control	4.2 a	103 a	639 a	364 a	21 a
Fertilized	4.9 a	109 a	565 a	343 a	24 a
Ground Cover					
Control	4.3 a	109 a	613 a	351 a	23 a
Herbicided	4.8 b	104 b	593 a	356 a	23 a

SITE II

Treatment	N	OM	Mineralizable N	Soluble Salts	pH
	(g kg^{-1})		(mg kg^{-1})		
Fertilization					
Control	0.98 a	20 a	22.2 a	129 a	5.0 a
Fertilized	1.18 a	21 a	12.7 a	134 a	4.9 a
Ground Cover					
Control	0.99 a	22 a	20.1 a	134 a	5.0 a
Herbicided	1.17 a	19 b	14.7 a	129 a	4.9 a

Treatment	P	K	Ca	Mg	Mn
	(mg kg^{-1})				
Fertilization					
Control	2.9 a	69 a	565 a	214 a	24 a
Fertilized	3.1 a	69 a	521 a	218 a	27 a
Ground Cover					
Control	3.0 a	73 a	559 a	222 a	24 a
Herbicided	3.0 a	66 b	527 a	209 a	26 a

† Means within a treatment for each site followed by the same letter are not significantly different (Duncan's multiple range test; $\alpha = 0.1$).
§ Significant fertilizer × ground cover interaction; $\alpha = 0.1$.

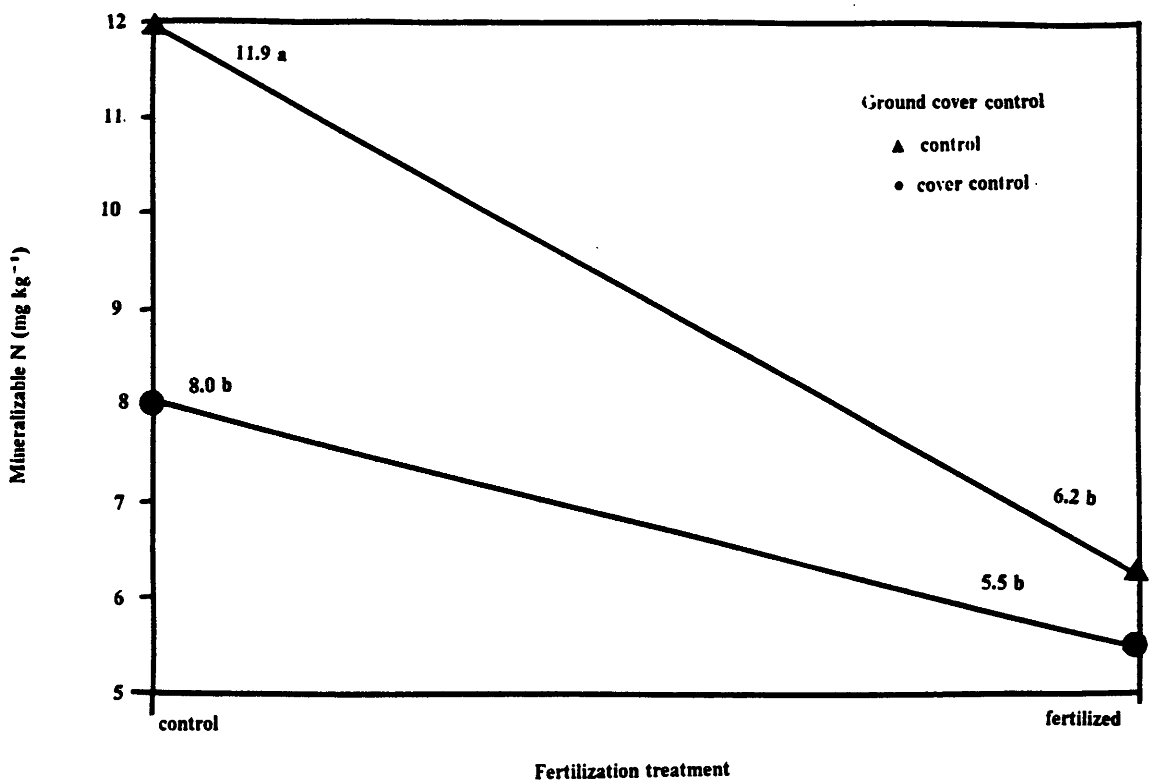

Figure 3. **Fertilizer and ground-cover effects on mineralizable N levels of Site I of two surface-mined sites in southwestern VA.**

Relationship Between Foliar Nutrition and Pine Volume-index

Nitrogen and P are often reported to be growth-limiting nutrients in mine soils (Bengtson and Mays, 1978; Plass, 1978; Curtis, 1978; Vogel, 1973). Correlations of fifth-year tree volume-index with age-five foliar N, P, K, Ca, and Mg revealed a negative relationship between loblolly and Virginia pine volume-indices and foliar N on Sites I and II and Site II, respectively. A positive relationship between white pine volume-index and foliar P was found on Site II. No relationships for the cations were evident. The relationship between tree volume-index and foliar N for loblolly pine on both sites was inverse (Figure 4 a & b). The same relationship occurred with Virginia pine on Site II (Figure 4 c), but it was not significant on Site I. As tree volume-index increased, a decrease in the foliar N level occurred. Those trees receiving the most intensive treatment (fertilization and ground-cover control) had the lowest foliar N levels, while producing the greatest volume-index. By contrast, the smaller control trees had the highest foliar N levels. Since third- and fifth-year foliar N levels for these two species (Table 7 & Table 8) were above reported critical levels in all trees (Table 10), this relationship suggested that N is not a growth limiting factor for loblolly and Virginia pines on these sites; rather, a nutrient dilution effect occurred in the larger trees. The larger tree volume-index resulted in lower concentrations of nutrients in a larger foliar mass; however, there was more total N accumulated in the tree biomass.

There was a positive linear relationship between white pine volume-index and foliar P on Site II; it was not significant on Site I (Figure 5). There was no age-five fertilizer response and foliar-P levels were below a critical level of 1.8 g kg^{-1} on Site II at age five, suggesting that P may be limiting white pine growth at age five and that a single 21 gram fertilizer pellet applied at planting no longer meets the P needs of the

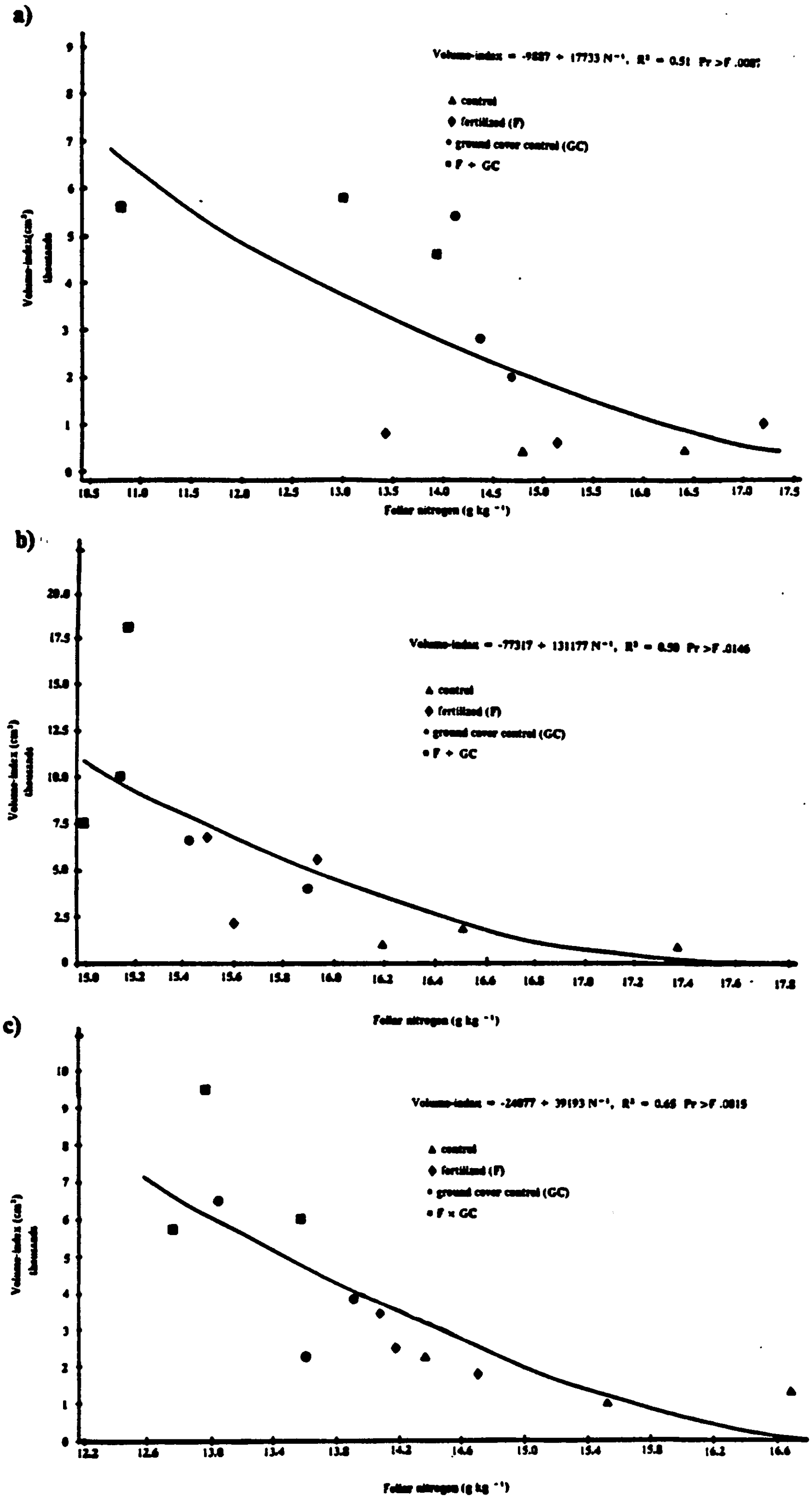

Figure 4. **Relationship between pine volume-index and foliar N levels on two surface-mined sites in southwestern VA.: a) loblolly pine on Site I; b) loblolly pine on Site II; c) Virginia pine on Site II**

trees. The extractable P level of this site was below 5 mg kg^{-1} which suggests that the available P supply may be marginal.

As these mine soils have aged, their ability to supply N and P to trees was altered, and the foliar nutrient status of the trees reflected this. At age one, foliar N levels less than the critical level of 12 g kg^{-1} for loblolly and Virginia pines and 18 g kg^{-1} for white pine, suggested that N may be limiting growth. With time, the N status of the sites has improved and foliar N of all species were at or above critical levels at age five (Table 7, Table 8, & Table 9) (NCSU, 1985; Berry and Marx, 1980; Bengtson and Mays, 1978; Wells *et al.*, 1973; Wells, 1970; Sucoff, 1961; Fowells and Krause, 1959). Both fertilization and ground-cover control and vigorous stands of serecia lespedeza have influenced the N status of the sites through an increased supply of N from fertilization, a reduction early on in competition for N between trees and ground cover, and an increase in N-fixation as the sites aged and stands of serecia lespedeza matured, all leading to increased N availability through improved N cycling. On the other hand, P appears to be more limiting with age on Site II. Lower levels of soil P (6.19 mg kg^{-1} and 3.00 mg kg^{-1} at stand age zero and five, respectively) are reflected in low P levels in white pine foliage (1.6 g kg^{-1}). Higher tree volume-index associated with higher foliar P levels suggested that P became more limiting as it was fixed by abundant Fe-oxides.

Fertilization and Ground Cover Effects on Foliar Nutrients

Loblolly pine

Foliar nutrient concentrations were used to assess treatment effects on tree response. Fertilization did not affect foliar N levels of loblolly pine at age one or three

Table 7. Foliar nutrient levels of loblolly pine grown on two surface-mined sites in southwestern VA.

SITE I			
Nutrient	Age 1†	Age 3	Age 5
	g kg^{-1} (SE)‡		
N	12.0 (0.67)	15.7 (0.25)	14.5 (0.50)
P	1.2 (0.04)	1.5 (0.03)	1.4 (0.02)
K	5.0 (0.12)	5.3 (0.13)	4.8 (0.09)
Ca	3.3 (0.11)	2.3 (0.09)	2.2 (0.11)
Mg	2.0 (0.07)	1.1 (0.05)	1.0 (0.04)
SITE II			
Nutrient	Age 1†	Age 3	Age 5
	g kg^{-1} (SE)		
N	17.7 (0.84)	14.2 (0.42)	15.7 (0.24)
P	1.8 (0.05)	1.6 (0.02)	1.6 (0.02)
K	5.1 (0.07)	5.6 (0.14)	4.8 (0.08)
Ca	3.2 (0.06)	3.0 (0.13)	1.9 (0.07)
Mg	1.7 (0.06)	1.4 (0.05)	0.9 (0.03)

† From Schoenholtz, 1983.
‡ Values in parantheses are standard errors of the means.

Table 8. Foliar nutrient levels of Virgina pine grown on two surface-mined sites in southwestern VA.

SITE I			
Nutrient	Age 1†	Age 3	Age 5
	----------g kg^{-1} (SE)‡----------		
N	10.7 (0.80)	16.2 (0.59)	14.0 (0.54)
P	1.1 (0.05)	1.5 (0.04)	1.4 (0.05)
K	4.2 (0.25)	4.9 (0.19)	4.5 (0.13)
Ca	3.7 (0.16)	3.2 (0.45)	2.2 (0.07)
Mg	2.4 (0.11)	1.4 (0.17)	1.0 (0.04)
SITE II			
Nutrient	Age 1†	Age 3	Age 5
	----------g kg^{-1} (SE)----------		
N	14.6 (0.51)	14.1 (0.41)	14.1 (0.32)
P	1.6 (0.07)	1.6 (0.03)	1.4 (0.03)
K	5.2 (0.19)	4.6 (0.08)	4.0 (0.08)
Ca	3.5 (0.15)	4.0 (0.06)	1.8 (0.06)
Mg	2.1 (0.10)	1.9 (0.02)	0.9 (0.02)

† From Schoenholtz, 1983.
‡ Values in parantheses are standard errors of the means.

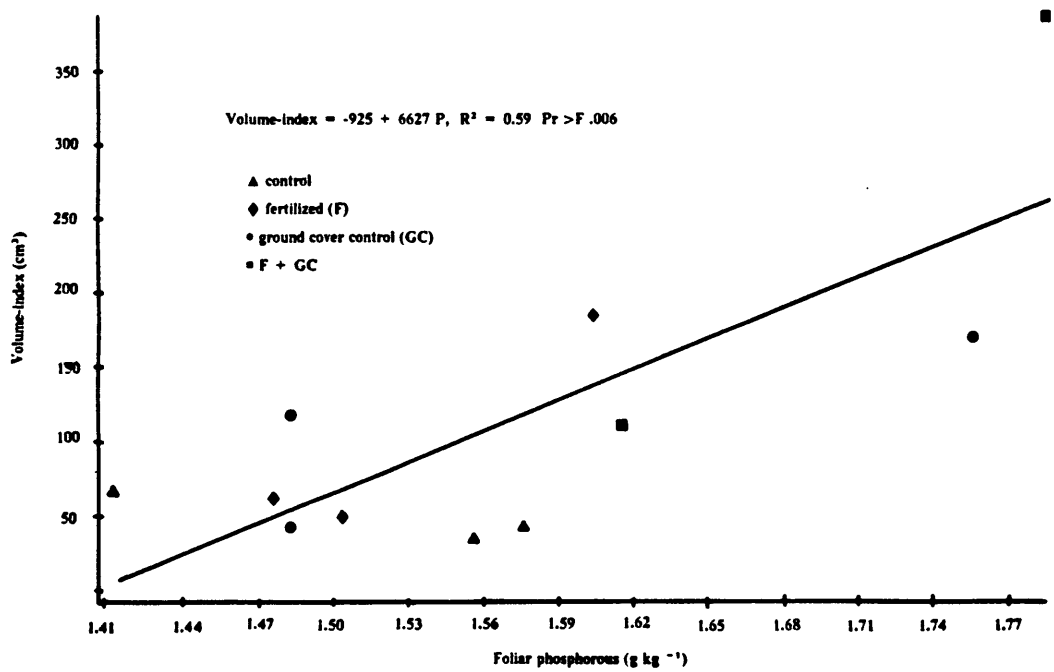

Figure 5. Relationship between white pine volume-index and foliar-P levels on Site II of two surface-mined sites in southwestern VA.

Table 9. Foliar nutrient levels of white pine grown on two surface-mined sites in southwestern VA.

SITE I			
Nutrient	Age 1†	Age 3	Age 5
	g kg^{-1} (SE)‡		
N	13.0 (0.90)	16.8 (0.37)	17.4 (0.54)
P	1.6 (0.08)	1.6 (0.03)	1.9 (0.06)
K	3.6 (0.20)	4.7 (0.16)	4.6 (0.07)
Ca	4.6 (0.15)	4.0 (0.52)	4.7 (0.17)
Mg	2.9 (0.11)	1.6 (0.11)	1.9 (0.06)

SITE II			
Nutrient	Age 1†	Age 3	Age 5
	g kg^{-1} (SE)		
N	15.5 (0.64)	14.1 (0.55)	16.7 (0.42)
P	1.6 (0.08)	1.7 (0.05)	1.6 (0.04)
K	3.4 (0.14)	4.3 (0.44)	4.6 (0.10)
Ca	5.3 (0.14)	5.0 (0.50)	3.6 (0.19)
Mg	2.8 (0.12)	2.3 (0.23)	1.6 (0.02)

† From Schoenholtz, 1983.
‡ Values in parantheses are standard errors of the means.

Table 10. Critical levels of loblolly, Virginia, and eastern white pines grown in natural soils.

Nutrient	lobolly pine.†	Virginia pine†	white pine§
	---g kg^{-1}---		
N	12.0	12.0	15.0-20.0
P	1.1	1.1	1.8
K	3.6	3.6	5.0
Ca	1.8	1.8	4.5
Mg	0.8	0.8	1.0-1.5

† Wells *et al.*, 1973; Wells, 1970; Sucoff, 1961; Fowells and Krause, 1959.
§ NCSU, 1985.

(Table 11 & Table 12). At age one, removal of competing vegetation increased foliar N levels on Site I (10.1 versus 13.8, g kg^{-1} control and herbicided, respectively). Schoenholtz (1983) reported that N limited first year growth, reflecting the competition of herbaceous vegetation for soil nutrients. However, on Site I at age three, the reverse occurred. Trees released from ground-cover competition had lower levels of foliar N (16.0 versus 15.5 kg^{-1} control and herbicided, respectively), suggesting that herbicide application prior to the third growing season improved tree growth. The effect of ground-cover control prior to the third growing season was also seen in an 87% increase in volume-index of released trees on Site I at age five. Nitrogen levels in the foliage have been diluted in a larger foliar biomass of released trees.

At age five, the effects of previously applied fertilizer and cover-control treatments on tree volume-index are reflected in a decrease in foliar N on Site II (Figure 6). Higher levels of foliar N were observed in control trees and lower levels were observed in treated trees, yet cover control improved tree volume-index on Site II, also suggesting a dilution effect. Treatments did not affect fifth-year foliar N on Site I.

While N was limiting tree growth at an early age (Schoenholtz, 1983), N dynamics of both sites have improved with time. Vigorous stands of sericea lespedeza have built up an organic layer through time and fixed N to improve overall N cycling. Previously-applied fertilizer and ground-cover control treatments improved the growth of loblolly pine and lower foliar N levels were observed due to a dilution effect. Mineralizable N levels in the soil show a similar relationship with tree volume-index. Higher levels of both mineralizable and foliar N were found in control plots, while lower levels were found in plots receiving the herbicide application (Figure 3 & Figure 6, respectively), again suggesting a dilution effect.

The dilution effect is commonly observed when foliar nutrient levels are at or above sufficiency levels. That is, the larger trees that have responded to ground-cover

Table 11. Cultural treatment effects on first-year foliar nutrient levels of loblolly pine on two surface-mined sites in southwestern VA.

SITE I†					
Treatment	N	P	K	Ca	Mg
	(g kg⁻¹)				
Fertilization					
Control	11.8 a‡	1.21 a	5.05 a	3.57 a	2.27 a
Fertilized	12.2 a	1.25 a	5.02 a	3.01 b	1.71 b
Ground Cover					
Control	10.1 a	1.15 a	5.12 a	2.95 a	1.98 a
Herbicided	13.8 b	1.31 b	4.95 a	3.63 b	1.99 a
SITE II					
Treatment	N	P	K	Ca	Mg
	(g kg⁻¹)				
Fertilization					
Control	15.8 a	1.74 a	5.12 a	3.30 a	1.92 a
Fertilized	19.5 a	1.88 b	5.02 b	3.10 a	1.47 a
Ground Cover					
Control	17.1 a	1.80 a	5.14 a	3.19 a	1.77 a
Herbicided	18.2 a	1.81 a	5.00 a	3.21 a	1.62 b

† From Schoenholtz, 1983.
‡ Means within a treatment for each site followed by the same letter are not significantly different (Duncan's multiple range test; $\alpha = 0.1$).
§ Significant fertilizer × ground cover interaction; $\alpha = 0.1$.

Table 12. Cultural treatment effects on third-year foliar nutrient levels of loblolly pine on two surface-mined sites in southwestern VA.

SITE I					
Treatment	N	P	K	Ca	Mg
	----	----	---(g kg^{-1})---	----	----
Fertilization					
Control	15.7 a †	1.58 a	4.94 a	2.42 §	1.16 a
Fertilized	15.7 a	1.44 b	5.59 b	2.22	1.11 a
Ground Cover					
Control	16.0 a	1.55 a	5.13 a	2.38 §	1.17 a
Herbicided	15.5 b	1.47 a	5.40 a	2.26	1.11 a
SITE II					
Treatment	N	P	K	Ca	Mg
	----	----	---(g kg^{-1})---	----	----
Fertilization					
Control	13.7 a	1.59 a	5.77 a	3.07 a	1.41 a
Fertilized	14.8 a	1.56 a	5.50 a	3.04 a	1.39 a
Ground Cover					
Control	14.6 a	1.65 a	5.77 a	3.16 a	1.36 a
Herbicided	14.0 a	1.54 a	5.56 a	3.00 b	1.42 a

† Means within a treatment for each site followed by the same letter are not significantly different (Duncan's multiple range test; $\alpha = 0.1$).

§ Significant fertilizer × ground cover interaction; $\alpha = 0.1$.

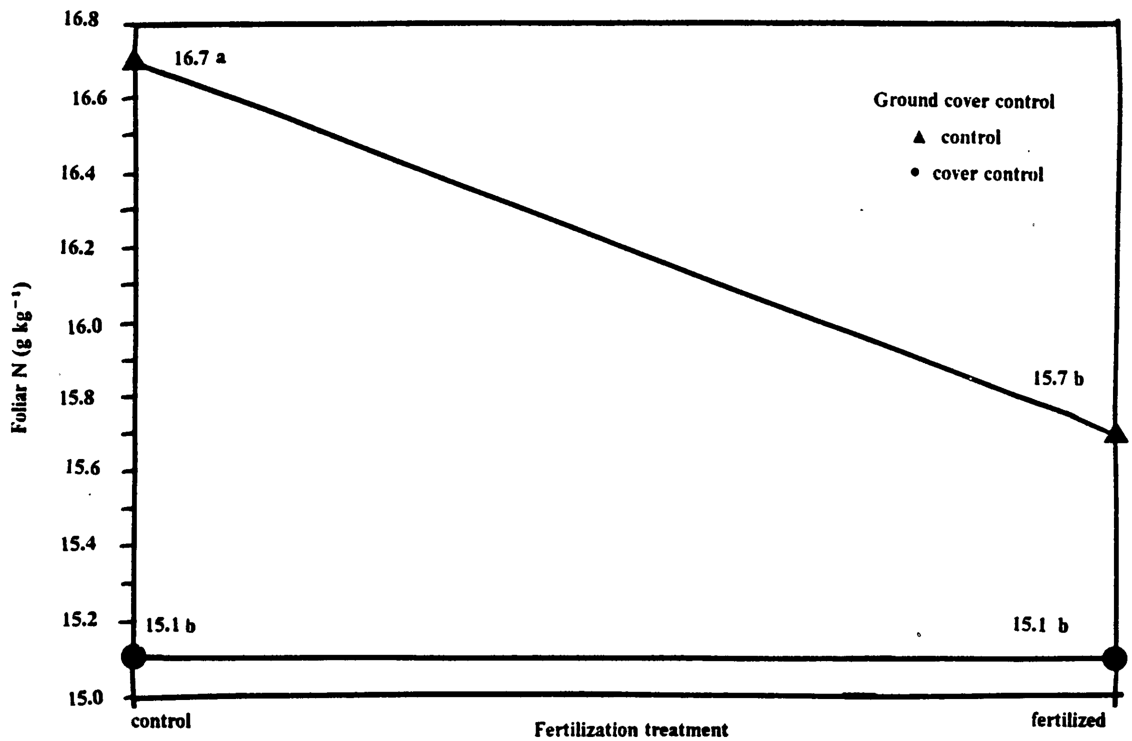

Figure 6. Fertilizer and ground cover effects on foliar N levels of loblolly pine on Site II of two surface-mined sites in southwestern VA.

control have lower (but still adequate) nutrient levels due to dilution in larger amounts of dry matter. The dilution phenomenon was better illustrated by the fact that untreated trees had higher levels of foliar N than treated trees while foliar N was at or above critical levels in all trees. With time, the initial cultural treatment responses were no longer reflected ir an increase in foliar nutrient levels; rather, a decrease in foliar nutrients was generally observed due to a dilution effect.

Lower foliar N levels in plots with ground-cover control may also be attributed to lower N availability through the elimination of the N-fixing serecia lespedeza. Bengtson and Mays (1978) found that serecia lespedeza can offer an alternative to repeated N fertilization on reclaimed sites. A remeasurement of their study showed that the benefits of serecia lespedeza on pine growth remained for both height and foliar N after 14 years (Mays and Bengtson, 1985). In the present study, ground-cover control did not eliminate ground cover completely from either site, but it may have caused a break in the N-cycle on the sites to create a decrease in the N supply. However, foliar N levels above the critical level of 12 g kg^{-1} did not suggest that N limited growth. Lower levels of foliar N were found in the most productive trees, those trees subjected to the most intensive treatment, while high levels of N were found in the least productive trees.

At age one, levels of foliar P were higher in fertilized trees than in control trees on Site II (1.74 versus 1.88 g kg^{-1}, respectively) (Table 11), showing that the trees have utilized the nutrients supplied by the fertilizer pellet. No effect of fertilization was seen on Site I. At age three, fertilized trees on Site I had lower foliar P levels (1.4 versus 1.6 g kg^{-1}, respectively) (Table 12) which may be attributed to a dilution effect. No effect of fertilization on foliar P was observed at age five. Ground-cover control increased levels of foliar P on Site I at age one and Site II at age five, suggesting that removal of competition for low levels of soil P allowed for greater plant uptake.

Table 13. Cultural treatment effects on fifth-year foliar nutrient levels of loblolly pine on two surface-mined sites in southwestern VA.

Treatment	N	P	K	Ca	Mg
SITE I					
	($g\ kg^{-1}$)				
Fertilization					
Control	15.2 a†	1.47 a	4.73 a	2.19 a	1.13 a
Fertilized	13.9 a	1.40 a	4.83 a	2.23 a	0.95 a
Ground Cover					
Control	15.6 a	1.44 a	4.79 a	2.47 a	1.08 a
Herbicided	13.5 a	1.44 a	4.77 a	1.95 b	0.99 a
SITE II					
	($g\ kg^{-1}$)				
Fertilization					
Control	15.9 §	1.59 a	4.68 a	1.77 a	0.94 a
Fertilized	15.4	1.56 a	4.90 b	1.95 a	0.89 a
Ground Cover					
Control	16.2 §	1.54 a	4.67 a	1.90 a	0.93 a
Herbicided	15.1	1.61 b	4.88 a	1.83 a	0.90 a

† Means within a treatment for each site followed by the same letter are not significanlty different (Duncan's multiple range test; $\alpha = 0.1$).

§ Significant fertilizer × ground cover interaction; $\alpha = 0.1$.

Slightly lower levels of K were seen on fertilized plots on Site II at age one (Table 11) and was slightly higher in fertilized trees on Site I at age three (Table 12) and on Site II at age five (Table 13). Foliar Ca and Mg were higher on non-fertilized plots on Site I at age one. Foliar Ca was lower in trees with ground-cover control on Site II at age three. Combined fertilizer and ground cover treatments affected foliar Ca at age three on Site I. At age five, foliar Ca was lower in trees with ground-cover control on Site I.

On both sites, the foliar P, K, Ca, and Mg levels were above critical levels associated with loblolly pine growing on natural soils (Table 10). Lower levels of foliar nutrients on herbicided plots are most likely due to an indirect foliar nutrient dilution response to larger amounts of foliar biomass on herbicided plots, rather than a direct treatment effect. These trends are similar to those observed for foliar N.

Virginia pine

Fertilization had a large effect on foliar nutrient levels of Virginia pine after one growing season, with the exception of foliar P on Site II (Table 14). Higher nutrient levels were found in fertilized trees, with the exception of Ca and Mg. Thus, the trees have taken advantage of the increased nutrient supply. This treatment continued to be reflected in an increase in Virginia pine volume-index due to fertilization on Site II at age five (Table 23).

Age-one foliar N and Mg on Site I were affected by combined fertilizer and ground-cover control treatments (Table 14). Higher N levels were observed in released trees. Foliar Mg levels were higher in control trees on Site I. Again, this shows that N was limiting at an early age and treatments helped to alleviate the deficiency and improve tree growth. Tree response to fertilizer and ground-cover control treatments were

Table 14. Cultural treatment effects on first-year foliar nutrient levels of Virginia pine on two surface-mined sites in southwestern VA.

SITE I†					
Treatment	N	P	K	Ca	Mg
	($g\ kg^{-1}$)				
Fertilization					
Control	8.3 ‡§	0.97 a	3.14 a	4.30 a	2.86 §
Fertilized	13.1	1.27 b	5.19 b	3.05 b	1.93
Ground Cover					
Control	9.8 §	1.07 a	4.04 a	3.59 a	2.41 §
Herbicided	11.7	1.16 a	4.29 a	3.76 a	2.39
SITE II					
Treatment	N	P	K	Ca	Mg
	($g\ kg^{-1}$)				
Fertilization					
Control	14.4 a	1.54 a	4.46 a	4.04 a	2.37 a
Fertilized	14.8 b	1.58 a	6.00 b	2.92 b	1.88 b
Ground Cover					
Control	13.6 a	1.56 a	5.06 a	3.58 a	2.09 a
Herbicided	15.6 a	1.56 a	5.40 a	3.38 a	2.15 a

† From Schoenholtz, 1983.
‡ Means within a treatment for each site followed by the same letter are not significantly different (Duncan's multiple range test; $\alpha = 0.1$).
§ Significant fertilizer × ground cover control interaction; $\alpha = 0.1$.

reflected in foliar N above the critical level at age five and a dilution of foliar N in greater tree volume. At age three, foliar P levels for Site I were lower in fertilized trees, due to a dilution effect. Similarly, on Site II foliar Mg levels were lower in herbicided plots due to a dilution effect (Table 15).

The dilution effect was again expressed in lower levels of K and Ca in Virginia pine foliage from fertilized plots on Site II (Table 16). Fertilization also improved tree growth on Site II (Table 23). As trees responded to the fertilizer pellet, the higher levels of nutrients present at age one were diluted over a greater biomass as the fertilized trees outgrew the control trees. These findings suggest that low mine soil fertility on Site II limited tree growth. Site II was older, more highly leached, and had less exchangeable cations and extractable-P levels (Table 5).

At age five, foliar N and Mg concentrations were lower in trees in herbicided plots than in control plots on Site I while P was lower in herbicided plots on Site II (Table 16). Control of ground cover increased N levels in foliage at age one by removing competition for this nutrient. However, at age five, trees within ground cover control plots were 88% larger than control trees on Site I (Table 23). As pine volume-index increased with release from herbaceous competition, tree response to ground-cover control was indirectly expressed in lower foliar nutrient levels due to dilution of nutrient content in a larger foliar biomass.

Eastern white pine

Fertilization interacted with the ground-cover control treatment to increase white pine foliar N at age one on Site I. Fertilization alone resulted in higher foliar N on Site II (Table 17). Higher levels of foliar N in the fertilized and herbicided plots suggested that N was limiting white pine growth at age one (Schoenholtz, 1983). No effect of

Table 15. Cultural treatment effects on third-year foliar nutrient levels of Virginia pine on two surface-mined sites in southwestern VA.

SITE I					
Treatment	N	P	K	Ca	Mg
	(g kg^{-1})				
Fertilization					
Control	16.8 a†	1.57 a	5.13 a	2.96 a	1.37 a
Fertilized	16.3 a	1.44 b	4.67 a	3.64 a	1.52 a
Ground Cover					
Control	17.4 a	1.47 a	4.88 a	2.86 a	1.50 a
Herbicided	15.9 a	1.57 a	4.96 a	3.58 a	1.39 a

SITE II					
Treatment	N	P	K	Ca	Mg
	(g kg^{-1})				
Fertilization					
Control	14.5 a	1.58 a	4.96 a	3.26 a	1.85 a
Fertilized	13.8 a	1.56 a	5.19 a	3.79 a	1.63 a
Ground Cover					
Control	14.6 a	1.60 a	4.95 a	3.56 a	1.84 a
Herbicided	13.7 a	1.53 a	5.19 a	3.47 a	1.64 b

† Means within a treatment for each site followed by the same letter are not significantly different (Duncan's multiple range test; $\alpha = 0.1$).

Table 16. Cultural treatment effects on fifth-year foliar nutrient levels of Virginia pine on two surface-mined sites in southwestern VA.

SITE I					
Treatment	N	P	K	Ca	Mg
	($g\ kg^{-1}$)				
Fertilization					
Control	14.2 a†	1.38 a	4.43 a	2.26 a	1.10 a
Fertilized	13.4 a	1.39 a	4.68 a	2.20 a	0.89 a
Ground Cover					
Control	15.2 a	1.44 a	4.62 a	2.42 a	1.14 a
Herbicided	12.8 b	1.34 a	4.48 a	2.09 a	0.90 b

SITE II					
Treatment	N	P	K	Ca	Mg
	($g\ kg^{-1}$)				
Fertilization					
Control	14.5 a	1.47 a	4.18 a	1.84 a	0.91 a
Fertilized	13.7 a	1.40 a	3.80 b	1.71 b	0.88 a
Ground Cover					
Control	14.9 a	1.48 a	3.92 a	1.84 a	0.92 a
Herbicided	13.3 a	1.39 b	4.06 a	1.70 a	0.87 a

† Means within a treatment for each site followed by the same letter are not significantly different (Duncan's multiple range test; $\alpha = 0.1$).

fertilization on foliar N was seen at age three or five (Table 18 & Table 19). Ground-cover control increased foliar N on Site II at age one. A treatment interaction effect was seen at age one on foliar P and Mg on both sites. Foliar P was highest on fertilized plots while Mg was highest on herbicided and control plots, suggesting that treatments improved nutrient availability at age one. Ground-cover control decreased foliar K on both sites and increased foliar Ca on Site I. No other treatment effects occurred.

At age three, foliar P, K, and Mg levels were affected by an interaction of fertilizer and cover control treatments, while foliar Ca was higher on herbicided plots (3.0 versus 5.1 g kg^{-1}, control and herbicided, respectively) (Table 18). No effect of treatment was observed for foliar nutient levels on Site II. The fertilizer and cover control interaction continued to be expressed in age-five volume-index on Site I. Combined treatments created a synergistic volume-index response (Table 26).

Fertilization had no effect on foliar nutrient levels of white pine at the end of five growing seasons (Table 19). Ground-cover control had a greater influence on fifth-year foliar nutrient levels. Foliar P was lower on herbicided plots (1.52 versus 1.67 g kg^{-1}, control and herbicided, respectively) on Site II. Dilution of foliar P in white pine occurred in those trees released from herbaceous competition. Foliar Ca was higher in herbicided plots on Sites I and II, suggesting that ground-cover control allowed for greater Ca uptake.

Foliar nutrient levels indirectly reflect species' response to treatments. As tree volume-indices were increased with both fertilization and ground-cover control, or a combination of these treatments, foliar nutrient levels, in general, decreased. The larger trees had lower (but still adequate) nutrient levels, due to dilution in larger amounts of foliage. Through fertilization and ground-cover control, the trees better exploited available water, nutrients, and light resources on these sites, and outperformed control trees.

Table 17. Cultural treatment effects on first-year foliar nutrient levels of white pine on two surface-mined sites in southwestern VA.

SITE I†					
Treatment	N	P	K	Ca	Mg
	(g kg⁻¹)				
Fertilization					
Control	9.7 ‡§	1.36 §	3.03 a	4.77 a	3.25 §
Fertilized	16.3	1.88	4.20 a	4.54 a	2.52
Ground Cover					
Control	12.2 §	1.75 §	4.03 a	4.22 a	2.81 §
Herbicided	13.8	1.48 a	3.20 b	5.09 b	2.96
SITE II					
Treatment	N	P	K	Ca	Mg
	(g kg⁻¹)				
Fertilization					
Control	14.1 a	1.59 §	3.23 a	5.35 a	3.24 §
Fertilized	17.0 b	1.53	3.50 a	5.17 a	2.45
Ground Cover					
Control	13.8 a	1.62 §	3.73 a	5.15 a	2.94 §
Herbicided	17.3 b	1.50	3.00 b	5.37 a	2.75

† From Schoenholtz, 1983.
‡ Means within a treatment for each site followed by the same letter are not significantly different (Duncan's multiple range test; $\alpha = 0.1$).
§ Significant fertilizer × ground cover interaction; $\alpha = 0.1$.

Table 18. Cultural treatment effects on third-year foliar nutrient levels of white pine on two surface-mined sites in southwestern VA.

SITE I					
Treatment	N	P	K	Ca	Mg
	($g\ kg^{-1}$)				
Fertilization					
Control	16.6 a†	1.49 §	4.64 §	3.26 a	1.38 §
Fertilized	17.1 a	1.63	4.82	4.83 a	1.93
Ground Cover					
Control	16.8 a	1.51 §	4.37 §	2.97 a	1.59 §
Herbicided	16.9 a	1.61	5.10	5.11 b	1.72

SITE II					
Treatment	N	P	K	Ca	Mg
	($g\ kg^{-1}$)				
Fertilization					
Control	14.3 a	1.66 a	4.03 a	5.07 a	2.29 a
Fertilized	13.9 a	1.64 a	3.67 a	5.55 a	2.70 a
Ground Cover					
Control	14.4 a	1.66 a	4.25 a	4.05 a	2.10 a
Herbicided	13.8 a	1.63 a	3.57 a	6.28 a	2.77 a

† Means within a treatment for each site followed by the same letter are not significantly different (Duncan's multiple range test; $\alpha = 0.1$).

§ Significant fertilizer × ground cover interaction; $\alpha = 0.1$.

Table 19. Cultural treatment effects on fifth-year foliar nutrient levels of white pine on two surface-mined sites in southwestern VA.

SITE I					
Treatment	N	P	K	Ca	Mg
	$(g\ kg^{-1})$				
Fertilization					
Control	16.7 a†	1.78 a	4.60 a	4.38 a	1.97 a
Fertilized	18.2 a	1.98 a	4.69 a	5.09 a	1.90 a
Ground Cover					
Control	17.8 a	1.85 a	4.78 a	4.45 a	2.02 a
Herbicided	17.1 a	1.90 a	4.50 a	5.02 b	1.86 a

SITE II					
Treatment	N	P	K	Ca	Mg
	$(g\ kg^{-1})$				
Fertilization					
Control	16.1 a	1.54 a	4.57 a	3.47 a	1.58 a
Fertilized	17.4 a	1.65 a	4.57 a	3.78 a	1.56 a
Ground Cover					
Control	16.7 a	1.67 a	4.59 a	3.40 a	1.55 a
Herbicided	16.8 a	1.52 b	4.55 a	3.85 b	1.58 a

† Means within a treatment for each site followed by the same letter are not significantly different (Duncan's multiple range test; $\alpha = 0.1$).

Cultural Treatment Effects on Pine Performance

Loblolly pine

Survival of loblolly pine by age five was not affected by fertilization on either site (Table 21). Ground-cover control helped trees survive on both sites by freeing the seedlings of overtopping vegetation and by limiting competition for water and nutrients. Above-average precipitation during the first growing season accounted for excellent first-year survival (97% on both control and herbicided plots), implying that ground-cover control at age three had a greater influence on survival at age five than earlier herbicide applications. Mycorrhizal inoculation had no effect on survival.

At stand ages three and five, fertilizer alone had no influence on the volume-index of loblolly pine on Site I (Table 20 & Table 21). Foliar nutrient concentrations above the critical levels for this species indicated an adequate nutrient supply, suggesting that the early influence of the fertilizer pellet diminished; that supplemental N fertilization was not necessary because N was not a growth limiting factor beyond age one; or that another factor limited pine growth, such as slope and aspect.

The ground-cover control treatment continued to influence tree volume-index on both sites. Volume of released trees was increased by 86 and 39% on Sites I and II, respectively. Researchers in the southern pine region have shown the effectiveness of weed control in stimulating growth and preventing mortality in young loblolly pine plantations (Michael, 1986; Wittwer *et al.*, 1986; Nelson *et al.*, 1981; Fitzgerald, 1982). Herbaceous weed control has been found to be especially effective in promoting first year growth when combined with fertilization (Neary *et al.*, 1985; Fitzgerald, 1982). Removal of competition for available light can also result in increased diameter growth.

Table 20. Third-year cultural treatment effects on loblolly pine performance on two surface-mined sites in southwestern VA.

SITE I			
Treatment	Volume†	Height	Diameter
	cm^3	---------------------cm--------------------	
Fertilization			
Control	99 a‡	46 a	0.88 a
Fertilized	113 a	58 a	0.88 a
Ground Cover			
Control	28 a	37 a	0.52 a
Herbicided	183 b	67 b	1.25 b

SITE II			
Treatment	Volume	Height	Diameter
	cm^3	---------------------cm--------------------	
Fertilization			
Control	291 a	62 a	1.6 a
Fertilized	806 a	91 a	2.4 a
Ground Cover			
Control	237 a	65 a	1.4 a
Herbicided	861 b	88 b	2.6 b

† Volume = Diameter^2 × Height.
‡ Means within a treatment for each site followed by the same letter are not significantly different (Duncan's multiple range test; $\alpha = 0.1$).

Table 21. Fifth-year cultural treatment effects on loblolly pine performance on two surface-mined sites in southwestern VA.

SITE I				
Treatment	Survival	Volume†	Height	Diameter
	percent	cm^3	------------------cm------------------	
Fertilization				
Control	84 a‡	3090 a	166 a	2.4 a
Fertilized	89 a	1884 a	129 a	3.2 a
Ground Cover				
Control	70 a	593 a	94 a	1.5 a
Herbicided	97 b	4380 b	201 b	4.0 b
Inoculation				
Control	87 a	2800 a	159 a	3.0 a
Inoculated	92 b	2170 b	136 b	2.6 a

SITE II				
Treatment	Survival	Volume	Height	Diameter
	percent	cm^3	------------------cm------------------	
Fertilization				
Control	79 a	2650 a	150 §	3.4 §
Fertilized	93 a	8380 a	222	5.4
Ground Cover				
Control	90 a	3110 a	162 a	3.5 a
Herbicided	92 b	7910 b	211 a	5.2 a
Inoculation				
Control	87 a	5770 a	186 §	4.4 §
Inoculated	87 a	5260 a	187	4.4

† Volume = $Diameter^2 \times Height$.
‡ Means within a treatment for each site followed by the same letter are not significantly different (Duncan's multiple range test; $\alpha = 0.1$).
§ Significant fertilizer × ground cover interaction; $\alpha = 0.1$.

Wittwer *et al.* (1986) found a strong correlation ($r^2 = 0.67$) between groundline diameter of loblolly pine and biomass of competing vegetation at the end of one growing season.

Nelson *et al.* (1981) found that pine seedling height response was related to percent ground cover, weed biomass, and precipitation. No first year response to herbicides was likely with high precipitation and low weed levels. After the first growing season of the present study, Schoenholtz and Burger (1984) noted that the lack of a strong weed control effect during the first year may be attributed to regular and abundant precipitation that occurred throughout the growing season on both sites. Average precipitation during the fifth growing season (1985) was below average (93.3 cm), in comparison to the first growing season (114.9 cm) when precipitation was well above the average of 95.15 cm. Moisture may have been more limiting during the fourth and fifth growing seasons, based on average precipitation values. This would accentuate the effectiveness of ground-cover control at the beginning of the third growing season.

Volume-index of trees not inoculated with mycorrhizae was 22% greater than inoculated trees on Site I. No mycorrhizal inoculation effect was seen on Site II. This response does not agree with the positive growth response of pines on mine soils to *Pisolithus tinctorous* (Pt) inoculation found by other researchers (Rothwell and Eagleston, 1984; Berry, 1982; Marx, 1980). Schoenholtz *et al.* (1987) reported that natural ectomycorrhizal infection (52%) on the present study sites may be adequate, eliminating the need for artificial inoculation. It may be that indigenous species are better adapted to this site than artificially introduced fungi. Preve *et al.* (1984) found that the establishment of inoculated loblolly pine may not be necessary for mine soils in this region due to ready infection by indigenous sources. The presence of antagonistic soil microorganisms can influence root growth of the host plant, as well as the survival of the symbiont (Pritchett and Fisher, 1987). High levels of foliar N in loblolly pine (Table 7) indicated that the N supply on this site was adequate. Growth suppression of inoculated pines with high N:P tissue ratios on P deficient sites has been reported. Reduction of growth can be caused by a reduction of mycorrhizal development and associated P absorption (Pritchett and Fisher, 1987).

The effects of fertilization and ground-cover control on tree growth response (relative volume-index response as a function of time through the five-year period) were studied. The shape of the response curve was analyzed to determine the effectiveness of individual treatments applied at different times during the five-year period. The inoculation treatment was not included since no positive response to this treatment was observed at the end of five-growing seasons.

The response of loblolly pine to fertilization, ground-cover control, and combined treatments is shown in Figures 7 and 8. Through this five-year period, a peak in response to treatments was seen at stand-age two for both sites. A slight improvement in volume-index was seen in response to ground-cover control at age five on Site I while a decrease in response to ground-cover control was seen on Site II, showing that site properties altered treatment effectiveness. Water availability was a primary control factor on Site I and removal of competition for water improved tree growth. Both sites exhibited a response to supplemental N fertilization; however, no significant fertilization effect was seen at age three or five, suggesting that supplemental N was an unnecessary treatment. This response also suggested that N-fixation by serecia lespedeza coupled with atmospheric inputs provide adequate N.

Combined treatments resulted in a similar response pattern but one of greater magnitude than individual treatments (Figure 8 a & b). Again, the greatest treatment response was seen at age two, emphasizing the importance of early treatments in improving the performance of this fast-growing pine species.

Response to ground-cover control treatment was greater on Site I than on Site II even though Schoenholtz and Burger (1984) reported higher soil water retention on

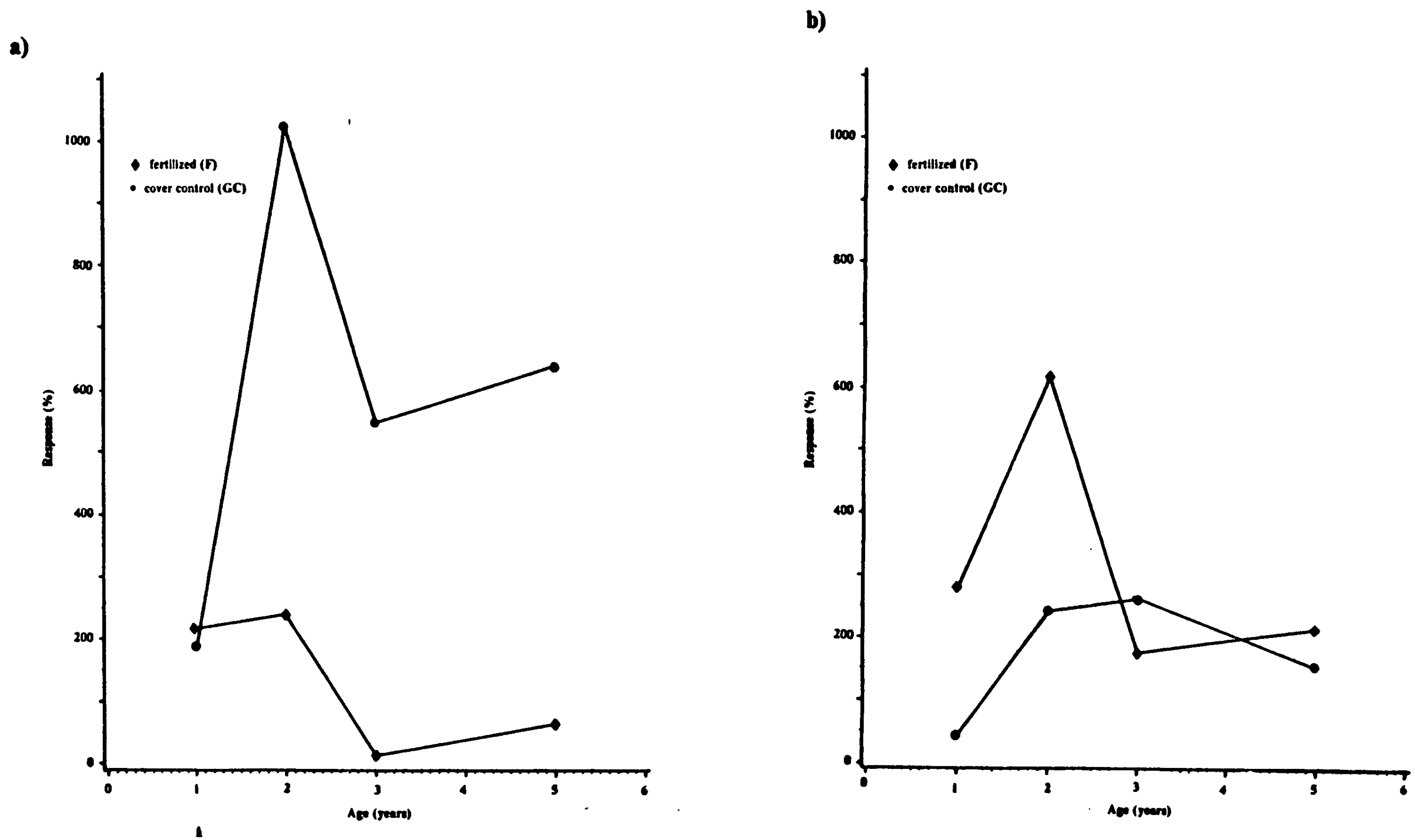

Figure 7. Response of loblolly pine to fertilization and ground-cover control on two surface-mined sites in southwestern VA.: a) Site I; b) Site II

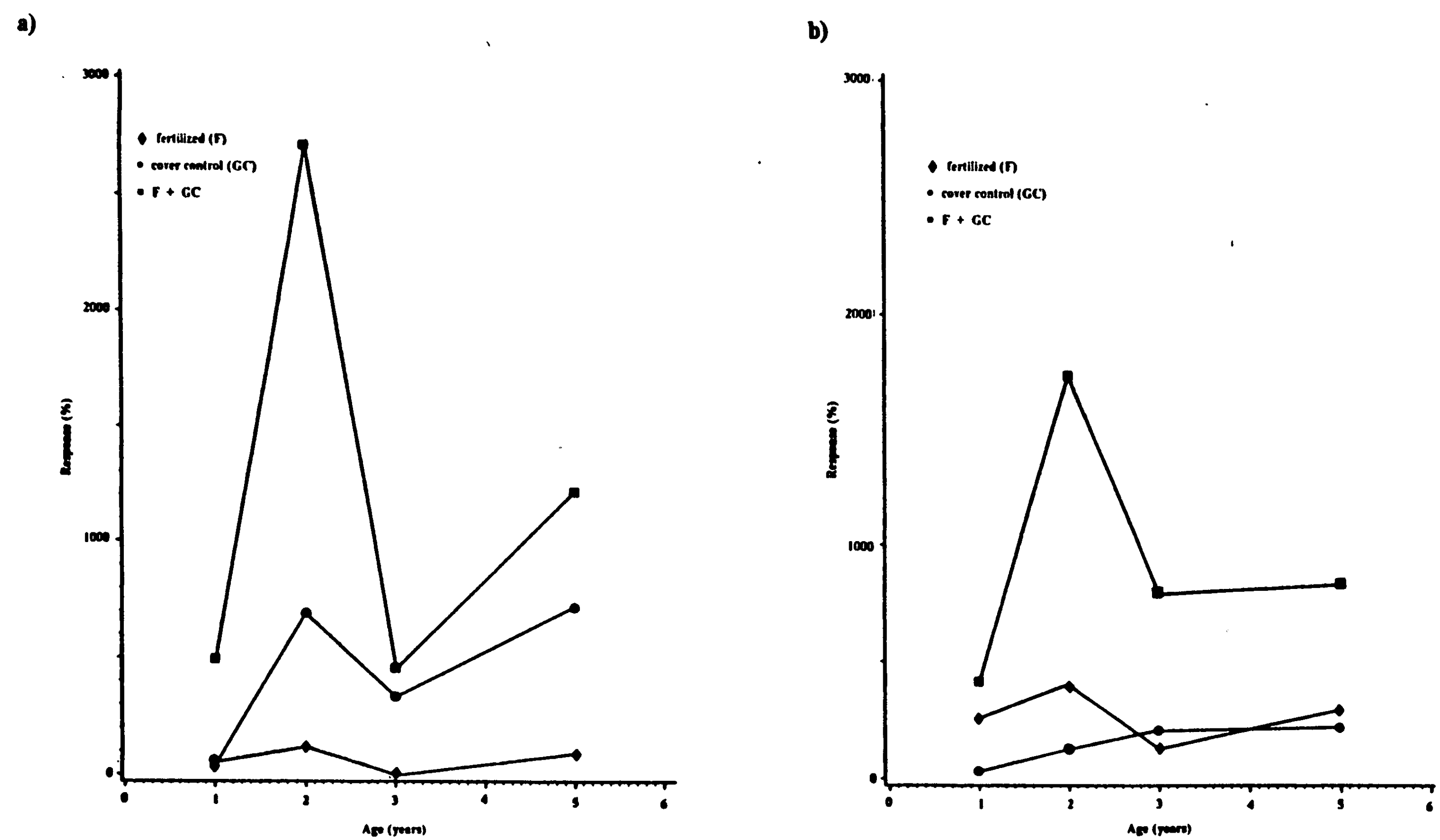

Figure 8. Response of loblolly pine to cultural treatments on two surface-mined sites in southwestern VA.: a) Site I; b) Site II

Site I. Three factors may be influencing the effectiveness of the ground cover control treatment on Site I: First, slope and aspect are known to effect site productivity. This site has a 38% slope, which expediated water movement. Sites with westerly aspects are usually drier than northerly and easterly (Pritchett and Fisher, 1987; Spurr and Barnes, 1980). Second, Kentucky-31 tall fescue continues to be a dominant herbaceous species on this site. Besides its demand for water, this species is known to have an allelopathic effect on tree growth (Walters and Gilmore, 1976). Third, though mine soil on the site was derived from predominantly siltstone overburden, high amounts of coarse fragments (49%) reduced the available water holding capacity on this site. Roberts (1986) reported low whole-soil water retention levels for similar mine soils.

Virginia pine

Fifth-year survival of Virginia pine on Site II was 84 and 94% in non-fertilized and fertilized plots, respectively. No effect of fertilization was seen on Site I (Table 23). Improving the nutritional status of the microsite around the tree may have allowed trees to get above the competing ground cover on Site II. Ground-cover control increased survival by 38% on Site I. Virginia pine, like loblolly pine, is a light sensitive species so it also responds to release from shading. Inoculated trees had poorer survival than non-inoculated trees on Site I. As was suggested for loblolly pine, this may be due to benefits of indigenous fungi species that are better adapted to site conditions than introduced Pt. No effects of ground cover and inoculation treatments on fifth-year survival were observed on Site II.

Average volume-index of five-year-old fertilized Virginia pine on Site II was 4890 cm^3 compared 2820 cm^3 for control trees; no fertilizer effect was observed on Site I. This indicated that the low fertility of Site II influenced the performance of this species.

Table 22. Third-year cultural treatment effects on Virginia pine performance on two surface-mined sites in southwestern VA.

SITE I			
Treatment	Volume†	Height	Diameter
	cm^3	cm	cm
Fertilization			
Control	27 a	30 §	0.6 §
Fertilized	284 a	65	1.3
Ground Cover			
Control	24 a	32 §	0.5 §
Herbicided	235 b	57	1.2

SITE II			
Treatment	Volume	Height	Diameter
	cm^3	cm	cm
Fertilization			
Control	172 a	54 a	1.2 a
Fertilized	484 b	81 b	2.0 b
Ground Cover			
Control	137 a	60 a	1.1 a
Herbicided	519 b	76 b	2.1 b

† Volume = $Diameter^2 \times Height$.
‡ Means within a treatment for each site followed by the same letter are not significantly different (Duncan's multiple range test; $\alpha = 0.1$).
§ Significant fertilizer × ground cover interaction; $\alpha = 0.1$.

Ground-cover control resulted in an 88% increase in volume-index over that on non-herbicided plots. An increase in volume-index was observed on Site II at age three (Table 22) though no effect of ground-cover control was seen at age five (Table 23). No effects of artificial mycorrhizal inoculation on fifth year volume-index were observed on either site.

Virginia pine is shade intolerant and seedlings require direct sunlight for good growth. It is also more tolerant of low soil moisture levels than most pines (Bennett *et al.*, 1978). Thus the Virginia pine on Site I has taken advantage of increased light and water availability associated with ground-cover control, and the treatments continued to influence tree volume-index through age five.

Site II is older in the sense of time-since-mining and has been subjected to soil-forming factors for a longer period of time. Availability of nutrients from the initial hydroseeding mix and from the spoil material itself tends to be lower than on Site I. However, mineralizable N levels were higher on this site, which would be expected for an older system that has had more time to build an organic layer and N cycle. Cations may have been leached, fixed, or tied up by the herbaceous vegetation, and mine soil fertility may play a greater role in Virginia pine productivity with time after mining.

Response of Virginia pine to treatments through this five-year period varied by site (Figure 9). On Site I, the greatest response to individual treatments was seen at age two with the ground-cover control treatment expressing a larger response than the fertilizer treatment. No increase in response to fertilization was seen at age five, suggesting that supplemental N fertilization was not necessary on Site I. In addition, no significant effect of fertilization on fifth-year volume-index (Table 23) was observed. On Site II, a peak in response to fertilization was seen at age two while a peak in response to ground-cover control was seen at age three. Supplemental N applied prior to the fourth growing season improved response at age five and a significant fertilizer effect

Table 23. Fifth-year cultural treatment effects on Virginia pine performance on two surface-mined lands in southwestern VA.

SITE I				
Treatment	Survival	Volume†	Height	Diameter
	percent	cm^3	---cm---	
Fertilization				
Control	76 a‡	550 a	85 a	1.3 §
Fertilized	89 a	4350 a	170 a	3.6
Ground Cover				
Control	59 a	440 a	83 §	1.2 §
Herbicided	95 b	3680 b	155	3.3
Inoculation				
Control	88 a	2130 a	121 a	2.4 a
Inoculated	76 b	2350 a	125 a	2.4 a

SITE II				
Treatment	Survival	Volume	Height	Diameter
	percent	cm^3	---cm---	
Fertilization				
Control	85 a	2820 a	154 a	3.4 a
Fertilized	94 b	4890 b	183 b	4.3 b
Ground Cover				
Control	84 a	2060 a	147 a	2.9 a
Herbicided	95 a	5650 a	190 a	4.8 a
Inoculation				
Control	92 a	4030 a	169 a	3.9 a
Inoculated	88 a	3680 a	168 a	3.8 a

† Volume = Diameter^2 × Height.
‡ Means within a treatment for each site followed by the same letter are not significantly different (Duncan's multiple range test; $\alpha = 0.1$).
§ Significant fertilizer × ground cover interaction; $\alpha = 0.1$.

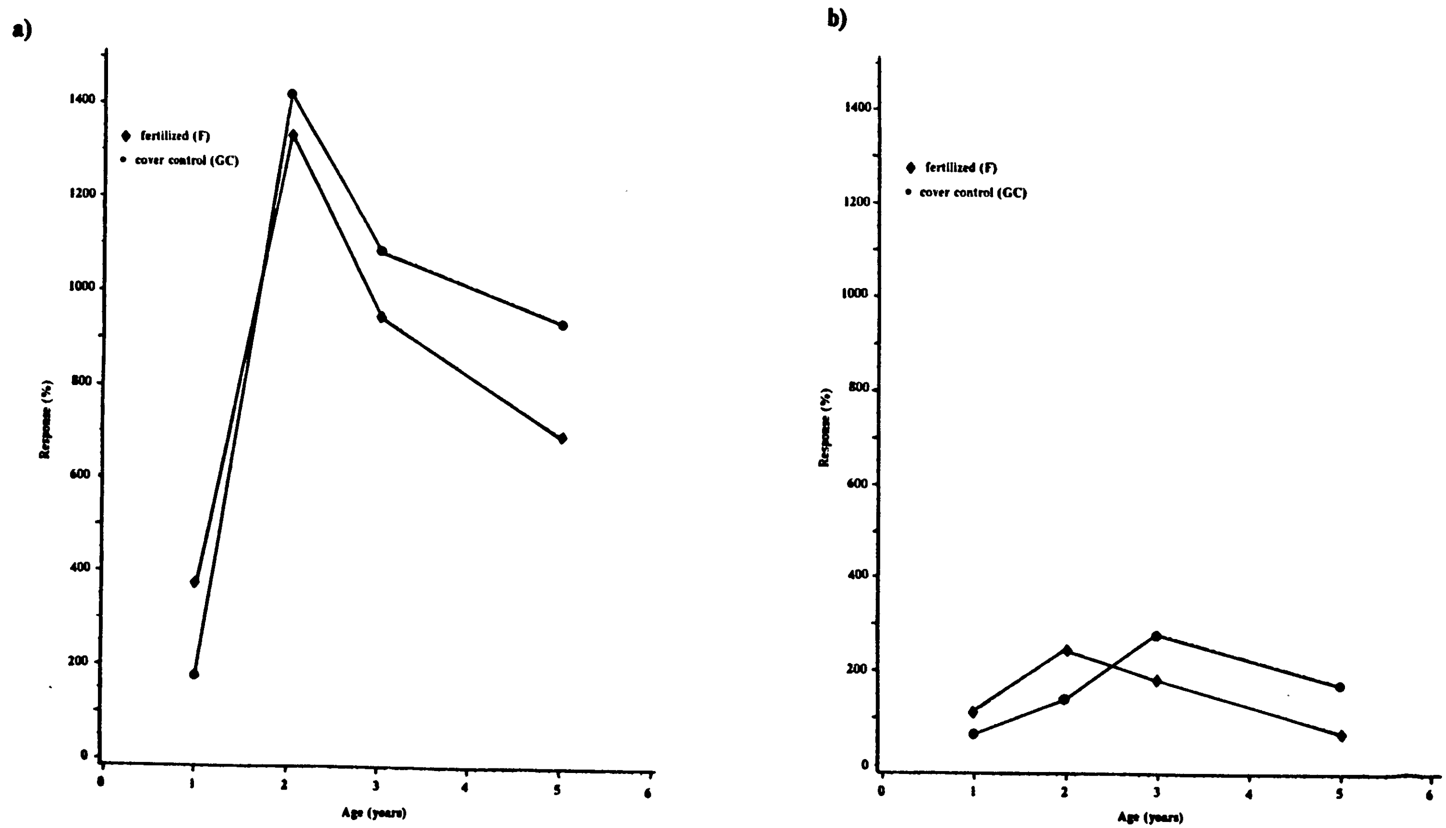

Figure 9. Response of Virginia pine to fertilization and ground-cover control on two surface-mined sites in southwestern VA.: a) Site I; b) Site II

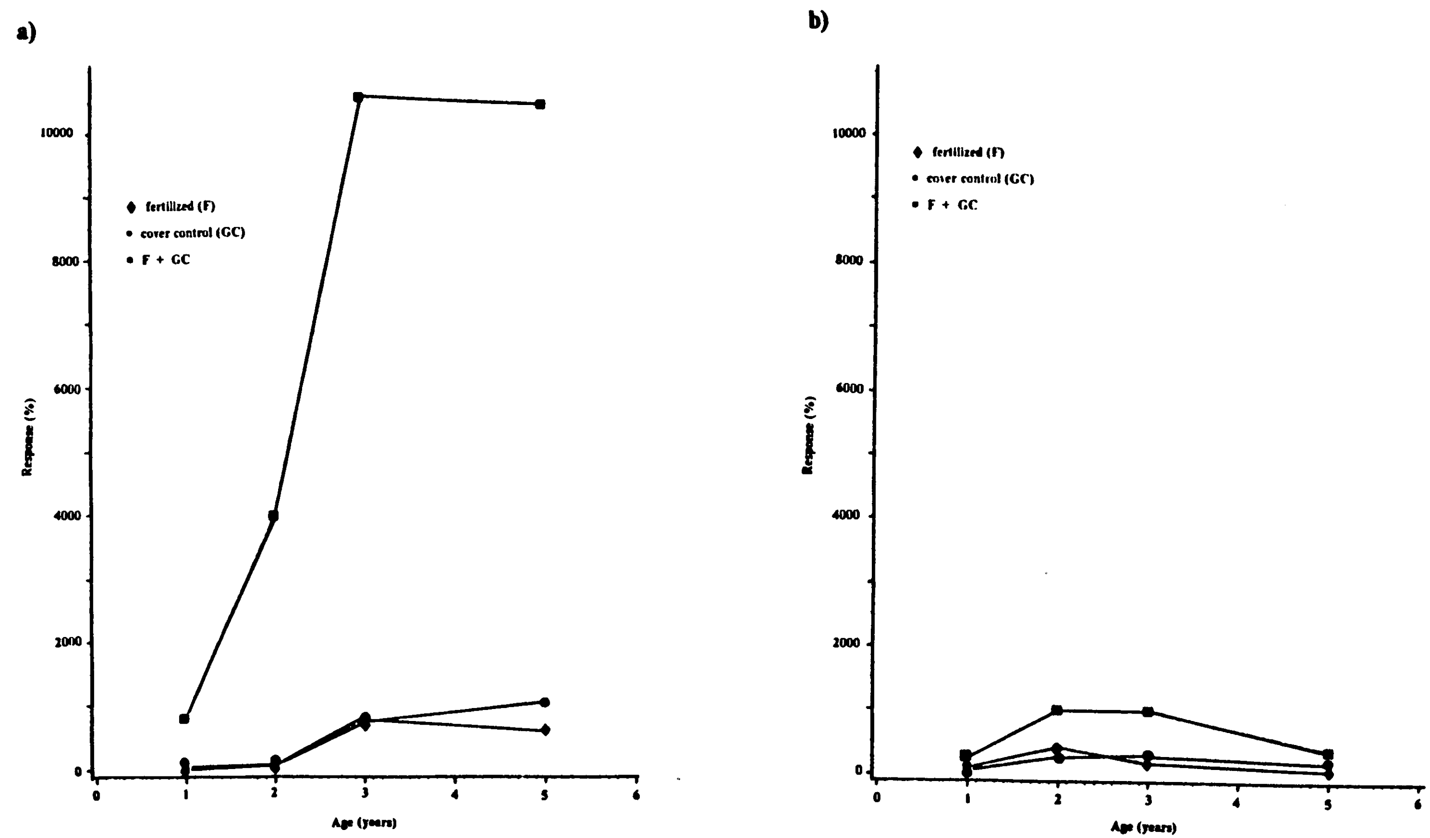

Figure 10. Response of Virginia pine to cultural treatments on two surface-mined sites in southwestern VA.: a) Site I; b) Site II

on volume-index was evident at age five on Site II (Table 23). However, foliar N levels above published critical levels suggest that N was not limiting.

Treatment interaction response showed the importance of combined treatments in improving tree growth. Figure 10 shows the important effect of these treatments at age three on Site I and at age two on Site II. Similar responses to individual treatments were observed, with combined treatments exhibiting the best response.

Fertilizer and ground-cover control treatments were both effective in improving productivity of Virginia pine by increasing available water, light, and nutrients. The strong effects of the individual treatments on pine growth on both sites stress the importance of fertilization and release when establishing this species on mined lands. While individual treatments improved tree growth, combining these treatments created a larger growth increase. Safaya (1977) noted that while plant response to fertilization may occur under conditions of adequate water availability, plant water-use efficiency (WUE) depends on adequate nutrients in the spoil. The importance of combining fertilization with weed control to allow full benefits of fertilization to be expressed in pine growth has been documented (Barnett and Tiarks, 1987; Neary *et al.*, 1985; Bengtson and Smart, 1981).

Eastern white pine

Survival of white pine after five growing seasons was not affected by the fertilization treatment on either site (Table 25). Ground-cover control increased survival of white pine by 38% on Site I by allowing the seedlings better access to light and water during the establishment phase; no effect was observed on Site II. No effect of mycorrhizal inoculation on survival was seen on either site.

Table 24. Third-year cultural treatment effects on eastern white pine performance on two surface-mined sites in southwestern VA.

SITE I			
Treatment	Volume†	Height	Diameter
	cm³	---cm---	
Fertilization			
Control	1.2 †§	13 §	0.3 §
Fertilized	5.2	18	0.4
Ground Cover			
Control	1.4 §	13 §	0.3 §
Herbicided	5.0	18	0.4

SITE II			
Treatment	Volume	Height	Diameter
	cm³	---cm---	
Fertilization			
Control	8 a	20 a	0.5 a
Fertilized	22 a	26 a	0.7 a
Ground Cover			
Control	7 a	23 a	0.5 a
Herbicided	22 b	24 a	0.7 b

† Volume = Diameter² × Height.
‡ Means within a treatment for each site followed by the same letter are not significantly different (Duncan's multiple range test; $\alpha = 0.1$).
§ Significant fertilizer × ground cover interaction; $\alpha = 0.1$.

By the end of five growing seasons, fertilization continued to interact with ground-cover control to improve white pine volume-index on Site I. A synergistic response to the combined treatments was seen at age three (Table 24) and continued through age five (Table 26). At age one, the combined treatments produced an additive effect on tree volume-index (Schoenholtz, 1983). On Site II ground-cover control alone resulted in a 74% greater volume-index at age five. Artificial mycorrhizal inoculation had no effect on white pine volume-index on either site.

White pine is especially susceptible to competition due to its slow early growth (Bennett *et al.*, 1978). To enhance seedling survival, weed control on mined sites is needed for one to two years. Continued weed control over a number of years will increase growth (Plass, 1978). White pine is a highly water and nutrient demanding species, thus, combined treatments will help meet these demands.

The early growth of white pine was not as impressive as that of the other two species; however, this species has some advantages over loblolly and Virginia pine. Planting white pine on reclaimed sites is receiving renewed interest because of its value for solid wood products, its ability to survive and grow well over a wide range of site and climatic conditions; its aesthetics; and as a preferred Christmas tree in this area (Davidson, 1985).

In contrast to loblolly and Virginia pines during the five-year period, a peak in white pine response to treatments did not occur. On both sites response to ground-cover control was slightly greater than response to fertilization (Figure 11). Response to combined fertilization and ground-cover control treatments was greater than individual treatments (Figure 12). A sharp increase in response to treatments at age five suggests that white pine has completed its slow growth phase and that treatments will have a greater effect on tree growth beyond this stage.

Table 25. Fifth-year cultural treatment effects on eastern white pine performance on two surface-mined sites in southwestern VA.

SITE I				
Treatment	Survival	Volume†	Height	Diameter
	percent	cm^3	----------cm----------	
Fertilization				
Control	50 a‡	11 §	25 §	0.4 §
Fertilized	71 a	118	45	0.9
Ground Cover				
Control	46 a	10 §	26 §	0.4 §
Herbicided	74 b	119	44	0.9
Inoculation				
Control	57 a	68 a	35 a	0.6 a
Inoculated	65 a	61 a	36 b	0.6 a

SITE II				
Treatment	Survival	Volume	Height	Diameter
	percent	cm^3	----------cm----------	
Fertilization				
Control	64 a	78 a	58 a	1.0 a
Fertilized	83 a	288 a	67 b	1.4 b
Ground Cover				
Control	72 a	73 a	53 a	0.9 a
Herbicided	76 a	284 b	62 a	1.5 b
Inoculation				
Control	78 a	158 a	55 a	1.1 a
Inoculated	70 a	199 a	60 b	1.2 a

† Volume = $Diameter^2 \times Height$.
‡ Means within a treatment for each site followed by the same letter are not significantly different (Duncan's multiple range test; $\alpha = 0.1$).
§ Significant fertilizer × ground cover interaction; $\alpha = 0.1$.

Table 26. Fifth-year interaction effect on white pine growth on Site I of two surface-mined sites in southwestern VA.

Treatment	Volume†	Height	Diameter
	cm^3	----------cm----------	
Control	2 b‡	23 b	0.3 c
Fertilization (F)	18 b	30 b	0.5 b
Ground Cover (GC)	20 b	28 b	0.5 b
F × GC	218 a	61 a	1.4 a

† Volume = $Diameter^2 \times Height$.

‡ Means within a column followed by the same letter are not significantly different (Duncan's multiple range test; $\alpha = 0.1$).

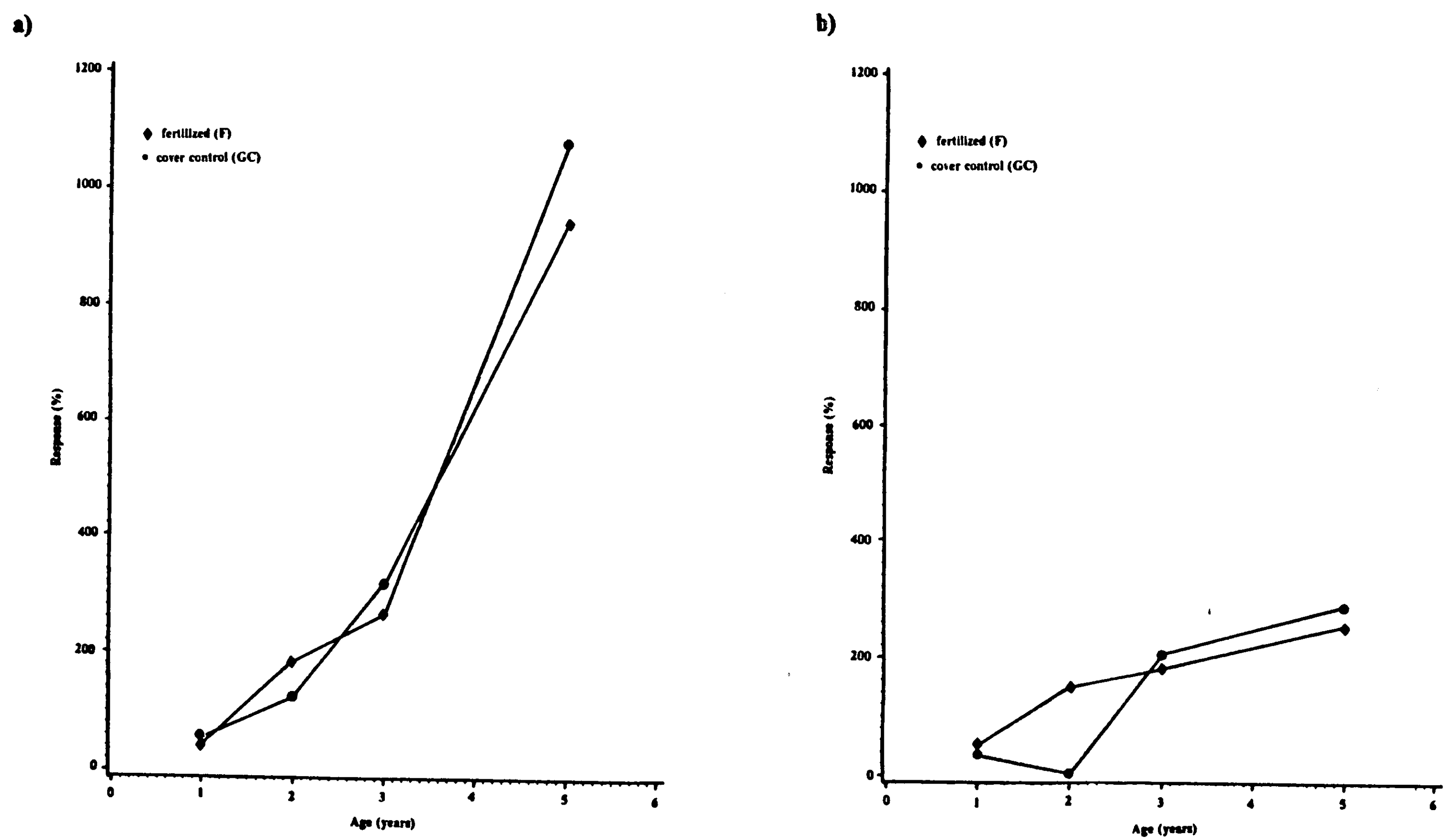

Figure 11. **Response of white pine to fertilization and ground-cover control on two surface-mined sites in southwestern VA.: a) Site I; b) Site II**

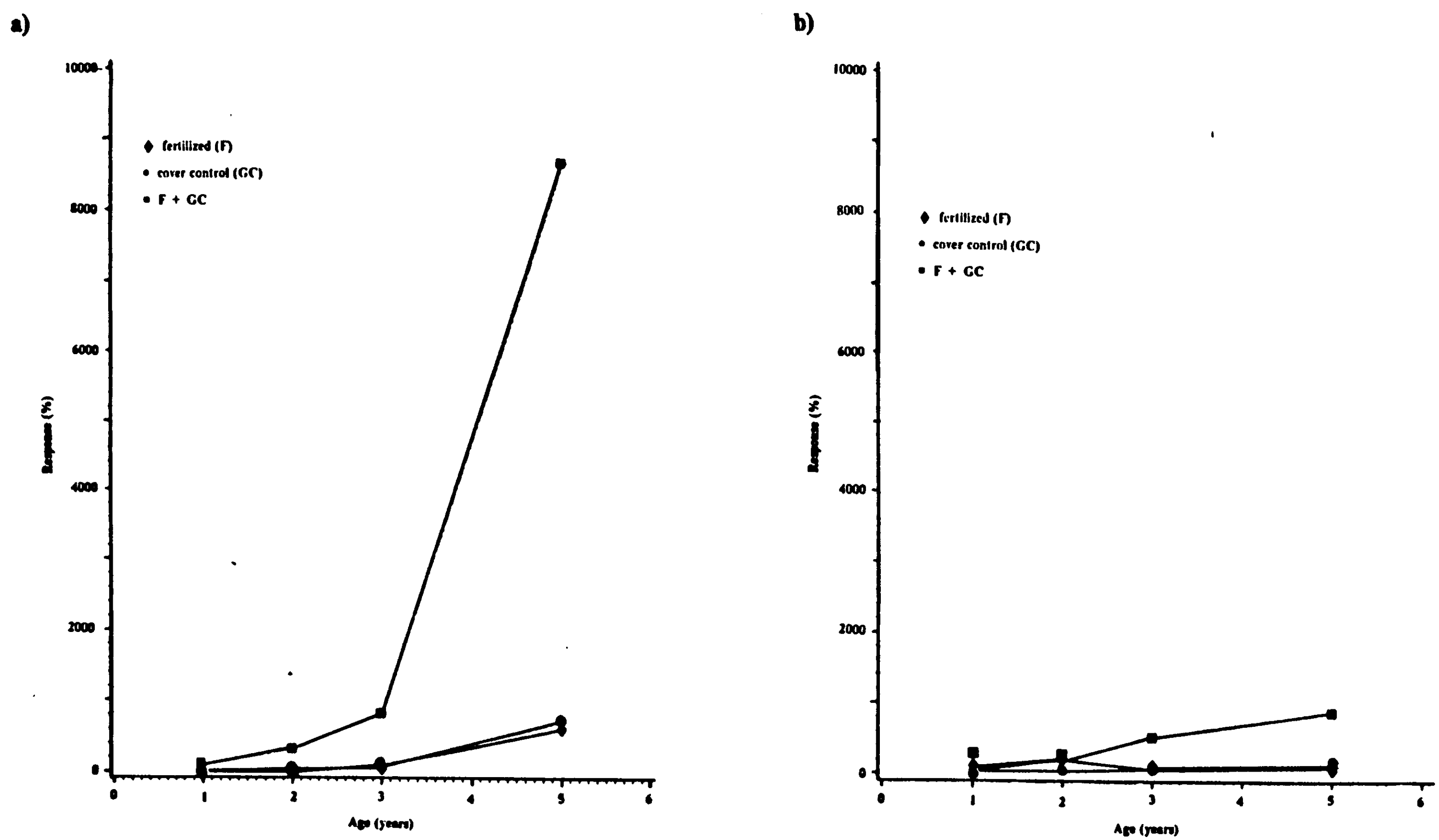

Figure 12. Response of white pine to cultural treatments on two surface-mined sites in southwestern VA.: a) Site I; b) Site II

The interaction of treatments was also very important for improving the growth of this species as seen by a synergistic response to combined treatments at age five on Site I, and large differences seen in response curves for Site I (Figure 12). The difference in percent response also showed that site properties affect tree growth and response to treatments, especially on a poorer site such as Site I.

A difference in soil moisture was seen on Site I during the first growing season due to the ground-cover control treatment, yet no moisture difference was seen on Site II. Increasing water availability made nutrients more available on Site I. Site characteristics make water availability less of a growth limiting factor on Site II. There was a compacted layer approximately 20 cm below the soil surface which restricted drainage but it did not appear to inhibit root penetration, and the flatness of the bench restricted surface runoff (Schoenholtz and Burger, 1984).

Mine soil fertility may play a role in white pine growth. Though no significant increase in volume-index was seen, fertilization has increased height and diameter of white pine on Site II. A linear relationship between foliar P and tree volume-index on Site II, and foliar P concentrations below critical levels also allude to a P deficiency.

Conclusion

After five growing seasons, cultural treatments continued to influence the growth of loblolly, Virginia, and eastern white pines on two surface-mined sites in southwestern Virginia. Differing site and soil properties caused the overall growth of pines and their response to treatments to differ on the two sites. Drier, less productive conditions were associated with the steep slope and westerly aspect on Site I, while on Site II mine soil chemical properties influenced pine performance. Thus pine growth was greater on Site

II, while response to treatments was more pronounced on Site I, the poorer of the two sites.

Differences in foliar nutrient levels of all species due to treatment emphasize the importance of fertilization and ground-cover control in improving tree growth. A negative relationship between loblolly and Virginia pine volume-index and foliar N levels showed a dilution effect, with lower nutrient levels found in trees with greater biomass. In addition, foliar N concentrations were above critical levels suggesting that N is not limiting growth. Thus N fertilization prior to the fourth growing season was not necessary, and vigorous stands of N-fixing serecia lespedeza coupled with natural atmospheric deposits may be supplying adequate N to both sites. A positive relationship between white pine volume-index and foliar P concentration suggested that P may be limiting growth on Site II. White pine foliar P concentration on this site was below the reported critical level for white pine, and soil P levels decreased with mine soil aging. Thus, ground-cover control at age five on Site II continued to influence white pine growth through the elimination of competition between the tree and P-demanding legumes for low levels of soil P. In turn, this relationship was evident in better tree volume-index.

Through the end of this five-year period, a time that coincides with eligibility for bond release, the combined fertilization and ground-cover control treatments have improved the growth of all species over the control. Response curves show that combined fertilizer and ground-cover treatments have a greater effect on tree growth than either individual treatment. Ground-cover control alone had the greatest effect on fifth-year loblolly pine growth, emphasizing the importance of water in the growth of this species. Early peaks in relative response to treatments show the importance of first-year treatments in stimulating the productivity of this fast-growing species. Virginia pine responded similarly to treatments on both sites, suggesting that site differences did not play a major role in affecting Virginia pine response to treatments, as would be expected from this less site demanding species. White pine, a more site-demanding species, showed greater treatment response on Site I, the poorer of the two sites. At age five, a synergistic volume-index response to combined fertilizer and ground-cover control treatments was observed on Site I, while on Site II ground-cover control improved the volume-index of white pine. Volume-index response to treatments suggest that white pine was just beginning to respond to treatments on both sites, once the trees came out of their early slow growth phase.

Results of this study also suggest that artificial inoculation of pine seedlings with Pt in the greenhouse is not beneficial, and in some cases, may be detrimental to tree growth. Loblolly pine volume index on Site I was lower for inoculated trees. Indigenous mycorrhizal species play a greater role in inoculating tree roots and in turn improving growth than introduced species which may not be adapted to the site and mine soil conditions associated with surface-mined lands in southwestern Virginia.

Mined lands are complex systems with many interacting factors influencing reforestation success. This study shows that fertilization and ground cover control can be employed to help overcome constraints to reclamation success. Problems of water and nutrient availability can be alleviated through fertilization and ground cover control treatments at the early stages of establishment and still be expressed at time of bond release and beyond.

Summary

The Surface-Mining Control and Reclamation Act of 1977 (SMCRA) set nationwide standards for the reclamation of surface-mined lands and provisions for the reclamation of abandoned surface-mines. Prior to the commencement of mining, a reclamation plan for the area must be developed and approved in accordance with this law. In the steeply sloping sloping Appalachian coalfields of Virginia, forestry is a primary post-mining land use. Dense, herbaceous vegetation required by SMCRA to protect sites from erosion can compete with planted tree seedlings for limited light, water, and nutrients. Competition from dense herbaceous cover is also a problem when sites reclaimed prior to application of SMCRA are put into other land uses such as forestry. Bond-release requirements established by SMCRA create a need for the use of cultural treatments that will guarantee the success of tree plantings at the time of eligibility for bond release. Hopefully, these same treatments will serve to improve tree growth beyond the five-year bond period.

Throughout the southeastern United States, herbaceous competition control and fertilization have been successful silvicultural treatments in commercial forestry operations on undisturbed soils. An evaluation of the response of commercial pine species (loblolly, Virginia, and eastern white pines) to the fertilization and herbaceous competition control on surface-mined land was the primary objective of this study. Positive responses to treatments after the first and second growing seasons have been reported by Schoenholtz and Burger (1984). This study evaluated these same treatments at the end of five growing seasons, a time that coincides with the time of eligibility for bond-release under SMCRA regulations.

Through a five-year period, pine performance and response of pines to cultural treatments differed on the two study sites. The first study site (Site I) was located in an area returned to AOC. The site had a westerly aspect and 38% slope. The mine soil was derived from predominantly siltstone overburden. The second site (Site II) was a flat bench site with approximately zero percent slope. The mine soil was derived from predominantly sandstone overburden and was was older than the mine soil on Site I based on time since mining. Site II supported a greater biomass than Site I for all species, due to drier, less productive conditions associated with the steep slope and westerly aspect of Site I. In turn, response to cultural treatments was more pronounced on Site I. Cultural treatments also indirectly influenced mine soil properties, by improving N dynamics of both sites through a priming effect, by increasing soil P levels on Site I through control of P-demanding legumes, and through the increase and/or decrease in soil cations due to accelerated weathering or increased plant uptake.

Foliar nutrient levels suggested that N did not limit growth of these pines at age five because levels of N were above critical levels for all species. Serecia lespedeza, a N-fixing cover present on both sites, coupled with atmospheric inputs, may have supplied adequate N for these pines. Negative relationships between foliar N concentrations of loblolly and Virginia pines and volume-index express a dilution effect. This dilution effect was expressed as lower foliar N concentrations found in trees subjected to the most intensive treatment which also had the greatest biomass and were at or approaching published critical levels. Foliar P levels of white pine were positively related to volume-index, suggesting that P may have limited growth on Site II. As this mine soil has aged, more P is fixed by abundant Fe-oxides, evidenced by a decrease in soil P with time.

Competition for light, water, and nutrients is lessened by the implementation of cultural treatments, as evidenced by differences in mine soil properties and foliar nutrient concentrations. At the end of five growing seasons, volume-index of loblolly pine on both sites continued to show a response to release from ground cover competition applied prior to the third growing season. This same increase in volume-index due to ground cover control was found at age three as well. Schoenholtz and Burger (1984) reported significant fertilization and ground-cover control interactions after the first and second growing season for loblolly pine. These findings exemplify the water-demanding nature of loblolly pine. A peak in volume-index response to treatment was seen at age two. This suggests that early herbaceous competition control was more important for improving the growth of loblolly pine and that release from herbaceous competition was more crucial to good growth than the addition of nutrients. No fifth year effect of fertilization was seen on either site, suggesting that N application prior to the fourth growing season was unnecessary. Vigorous stands of serecia lespedeza coupled with natural atmospheric deposition may provide adequate N. A negative effect of artificial mycorrhizal inoculation on loblolly pine volume-index at age five suggested that indigenous species are more important than introduced Pt in improving tree growth. No positive response to inoculation was seen for any species at age five, while a negative response was seen for volume-index of loblolly pine. Thus artificial inoculation with Pt is an unnecessary treatment for containerized pines planted on surface-mined sites in southwestern Virginia becasue indigenous mycorrhizal forming fungus species are plentiful and are better adapted to surface-mined sites in the region.

On Site I, ground cover control alone influenced Virginia pine volume-index after five growing seasons, while fertilization affected volume-index on Site II after five years. Generally, the response of Virginia pine to treatments peaked at age two for both sites, suggesting that the fertilizer pellet and ground-cover control treatments are important for improving growth of this species. No increase in response due to fertilization was observed between ages three and five, suggesting that N applied prior to the fourth growing season was not needed.

White pine was just beginning to respond to treatments at the end of five growing seasons. At the end of five growing seasons on Site I, a synergistic response of volume-index to combined treatments was found. On Site II, removal of competing vegetation increased the volume-index of white pine over that of the control. Response curves show no peak in response to treatment. These results demonstrate the importance of continuing treatments beyond one growing season, possibly until the time that white pine has completed its slow-growth phase. Again, no response to fertilization at age five indicated that N fertilization prior to the fourth growing season was not needed on Site II. White pine foliar N levels suggest that subsequent N treatment was not necessary on Site I; however, due to an interaction of fertilization and ground cover control white pine volume index on Site I, no conclusion can be drawn.

These drastically disturbed surface-mined lands are complex ecological systems. Lack of available nutrients and water greatly control the productivity of these sites. The constantly-changing soil system plays a major role in the supply of water and nutrients to trees on mined lands. This study shows that cultural treatments can be employed so that drastically disturbed systems can attain greater pine productivity levels in shorter periods of time than nature would allow.

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