HYDROSEEDING PINE-GRASS-LEGUME MIXTURES FOR EROSION CONTROL AND REFORESTATION OF MINE SPOILS

by

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(ABSTRACT)

Growth and mycorhizal colonization of surface-seeded pine (Pinus spp.) as affected by two mine-spoil types (siltstone and sandstone), two fertilizer levels (control and 100 kg/ha each of N, P, and K), and three mycorrhizal inoculation treatments (control, 56 kg/ha pine litter, and 250g/ha Pisolithus tinctorius spores) were evaluated in a greenhouse experiment. The effects of four nurse crops and three fertilizer levels on ground cover, spoil erosion, and establishment of hydroseeded pines on a recontoured strip-mine in southwestern Virginia were also studied.

In the greenhouse experiment, germination was highest (12, 55, and 34% for P. strobus, P. virginiana, and P. taeda, respectively) in non-fertilized siltstone, but

survival was highest (85, 100, and 95% for the same species) in non-fertilized sandstone. Seedlings grown in fertilized sandstone had significantly higher stem and root biomass than those in any other spoil and fertilzer combination. Mycorrhizal inoculation treatments were effective in sandstone but not in siltstone spoil.

In the field experiment, use of a nurse crop significantly increased ground cover over the controls, but addition of a nurse crop or fertilizer resulted in a decrease in pine establishment of at least 46%. The only nurse crop to obtain the minimum 75% ground cover required by law was a Lolium perenne, Festuca rubra, and Lotus corniculatus mixture which, at 60 kg N/ha, reduced spoil erosion by about 70% over the controls while still allowing the establishment of 6,000 trees/ha.

To my parents and Aunt Judith.

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INTRODUCTION

Coal mining using surface-removal techniques has increased in southwestern Virginia over the last 40 years. While reclamation of mined areas has included a variety of land uses, forestry has always been considered a feasible reclamation alternative. From 1966 to 1980, for example, over 18 million tree seedlings were planted on Virginia strip mines (Brown and Branson, 1980), since reclamation managers recognized that trees planted on mine spoils can generate monetary returns from the production of pulpwood, sawtimber, and other forest products. Among the species used in reclamation forestry, pines (Pinus spp.) are commercially valuable species that have shown good growth potential on strip-mined land (Plass and Burton, 1967).

During the 1970's public concern for the environmental impact of surface mining led to the enactment of an array of reclamation laws (Bowling, 1978), such as the 1977 Surface Mining and Reclamation Act (PL 95-87). The latter requires that mined land be returned to its approximate original contour, and established minimum ground cover requirements for a number of years following the end of mining operations.

These regulations have shifted the emphasis of reclamation towards non-silvicultural land uses (Smith, 1980) because the dense herbaceous cover required by strict erosion guidelines results in a microenvironment unfavorable for tree growth (Vogel and Berg, 1973). If forestry is to become important in reclamation again, grass-legume mixtures that control spoil erosion while allowing the growth of trees will have to be developed.

An additional problem involving the establishment of tree plantations on strip-mined land is the return-to-contour requirement of present reclamation law. The steep topography of recontoured mines in southwestern Virginia has precluded the use of machine planters. As a result of these legal and physical constraints, the most common reclamation practice in use today is the establishment of pastures by the hydroseeding of grass-legume mixtures.

Although previous attempts to establish commercially-valuable tree species such as pines by hydroseeding have not been successful (Czapowskyj and Writer, 1970; May et al., 1973), economic and environmental benefits could be derived from developing techniques that would allow the incorporation of a tree component to the hydroseeding process.

Reclamation managers also need to identify edaphic factors and cultural practices that will maximize their chances of successful reforestation. Knowledge of the composition and inherent properties of parent material is central in determining the need for lime, fertilizer, or physical amelioration.

Microbiological factors such as the presence of sources of mycorrhizal infection are also of importance. Pine seedlings infected with mycorrhizal symbionts survive and grow better than uninfected controls (Marx and Artman, 1979; Walker et al., 1981). Pisolithus tinctorius (Pers.) Coker and Couch (PT) is an ectomycorrhizal symbiont that is well adapted to acid mine spoils (Marx and Artman, 1979; Walker et al., 1981), but other symbionts may be more suitable for reforesting neutral or alkaline sites.

Although pine seedlings have been successfully inoculated in the nursery by the addition of fungal mycelium to their roots (Marx and Bryan, 1975), the use of a vegetative inoculum is probably not feasible when reforestation is to be accomplished by seeding. The addition of fungal basidiospores or forest floor litter to the soil or growth medium with pine seed have shown some promise as mycorrhizal inoculation techniques (Theodoru, 1970; Bengtson et al., 1973).

There is presently no information on the feasibility of establishing pine stands on recontoured strip-mines in southwestern Virginia by hydroseeding. Furthermore, the effects of herbaceous vegetation, physical and chemical characteristics of different spoils, and different sources of mycorrhizal inoculum on pine germination, growth and survival have not been well documented. This research was conducted to provide such information by establishing a greenhouse and a field experiment with the following objectives:

1. Determine the effectiveness of mycorrhizal inoculation of hydroseeded pines by the addition of spores or pine litter to different spoil types.
2. Identify hydroseeding mixtures of grasses and legumes that will minimize competition with trees and provide effective erosion control on mine spoils.
3. Quantify the erosion control benefits derived from the use of a herbaceous nurse crop in reclamation tree plantations.

LITERATURE REVIEW

Direct Seeding

Direct seeding of pines in the southeastern United States is a well documented forest establishment technique (Hinton, 1967; Mann, 1968; Russell and Mignery, 1968). Less is known, however, about the establishment of pines on mine spoils by direct seeding methods.

Thor and Kring (1964) compared spot-seeded loblolly pine (Pinus taeda L.) with plantings of the same species on coal spoils in Tennessee. Although percent survival and stocking after three years were significantly higher for the planted trees, the closer spacing of the seeded spots resulted in an equal number of surviving trees per hectare. The authors concluded that the main advantage of planting was a more uniform tree distribution.

Zarger and coworkers (1973a) repeatedly obtained satisfactory stands of loblolly, eastern white (Pinus strobus L.), shortleaf (Pinus echinata Mill.), and Virginia (Pinus virginiana Mill.) pine by helicopter-seeding on alkaline spoils in southwest Virginia. They recommended seeding rates of about 1.7 kg/ha for loblolly and eastern white pine, and 1.2 kg/ha for shortleaf and Virginia pine.

Plass (1974) drill-seeded seven pine species on 12 different mine spoils and evaluated their emergence, survival, and growth. Across all mine spoil types loblolly and longleaf (Pinus palustris Mill.) pine were the only species to have germination values comparable to those of control seed lots in a germinator. Moderate decreases between germinator and spoil occurred for shortleaf and Virginia pine, and large decreases occurred for eastern white, red (Pinus resinosa Ait.), and pitch (Pinus rigida Mill.) pine. Survival was highest in eastern white and lowest in red pine. Best growth was by loblolly, longleaf, and Virginia pine. The authors concluded that loblolly and longleaf pine are the species most suited for direct seeding on mine spoils.

Wittwer and coworkers (1979) spot-seeded Virginia pine on a mixed sandstone and shale coal-spoil in southeastern Kentucky. They obtained 14, 40, 41, and 70% first-year stocking when ameliorating the site without any amendments, with fertilizer, with bark mulch, and with both fertilizer and bark mulch, respectively.

Very few studies have been conducted on the feasibility of hydroseeding pines on mine spoils. Hydroseeding is a process by which a mixture of seeds is applied to an area in need of revegetation in the form of a water-mulch slurry

pumped from a mixing tank. Czapowskyj and Writer (1970) attempted to establish red and Scotch (Pinus sylvestris L.) pine on acid (pH 3.7-4.8) coal spoils in Pennsylvania but were not successful. May and coworkers (1973) failed to establish loblolly, longleaf, and slash (Pinus elliottii Engelm.) pine on a kaolin mine spoil in Florida due to competition from herbaceous vegetation.

Nurse Crops

Ground cover is required to minimize soil erosion from forest land (Dissmeyer and Foster, 1980), particularly when establishing tree plantations on disturbed sites such as mine spoils (Environm. Protect. Agency, 1973; Hill, 1978). In Virginia, state regulations require 75% ground cover for five years after mining before a reclamation bond is returned to a strip mining operator (Division of Mined Land Reclamation, 1979).

Because acceptable ground cover from trees is not obtained until about the time of crown closure, a nurse crop of herbaceous vegetation is required in the early stages of a forest reclamation rotation. Researchers agree on the need of such cover in mine spoil tree plantations (Carpenter and Albers, 1981; Vogel, 1980, 1981), but although Dissmeyer and Foster (1980, 1981) have designed both field methods and

analytical models for estimating erosion from forest land, information on the effects of different tree-herbaceous vegetation mixtures on soil erosion is lacking. Most of the research conducted on erosion of mine spoils has dealt with the watershed hydrology of large mining operations (Curtis, 1973; Hill, 1973).

But competition for site resources from herbaceous vegetation can have severe negative consequences on the growth of pine seedlings. Kramer and colleagues (1952) grew seedlings of loblolly and shortleaf pine under a canopy and in the open. They attributed the reduced survival and growth of the pine seedlings grown under canopy to competition for light. Nelson and coworkers (1981) observed twelve and four-fold increases in pine biomass as a result of weed control in 1-year old loblolly pine plantations in Arkansas and Oklahoma, respectively. Seedling height was significantly correlated to weed biomass and ground cover.

Faced with a tradeoff between tree growth and spoil erosion, reclamation managers can manipulate several biological components to achieve their reclamation goals. Vogel and Berg (1973) demonstrated the importance of species selection when working with nurse crops. In a trial where black locust (Robinia pseudoacacia L.) was seeded in conjunction with four different herbaceous mixtures,

survival and growth of tree seedlings were lower where cool-season, rapid growth grasses such as Italian ryegrass (Lolium multiflorum Lam.) and tall fescue (Festuca arundinacea Schreb.) were used. This was attributed to competition for light and moisture during early spring, when both grasses and trees were growing at their fastest rate. The authors suggested the use of warm season, or slow-growing cool season grasses.

Duffy (1974) confirmed these results by observing that pine survival and growth were depressed when a fast growing species such as weeping lovegrass (Eragrostis curvula (Schrad.) Nees) was used as a companion crop. Fingergrass (Digitaria eriantha), a slower growing, tillering grass, increased from 47 to 80% the survival of loblolly pine seedlings growing in a sandy spoil when compared with the lovegrass.

Two species that have shown promise as meeting the requirements of effective ground cover without excessive competition are perennial ryegrass (Lolium perenne L.) and red fescue (Festuca rubra L.). Perennial ryegrass makes quick growth to provide effective erosion control. It does not grow taller than 0.5 m, however, and because of its bunch growing habit it leaves bare spots of ground in between plants. It is better suited for use with companion

species than more competitive grasses such as annual ryegrass (Vogel, 1981).

Red fescue is a slower germinating species (Virginia Tech Extension Division, 1976), and is a sod former that spreads by rhizomes (Martin et al., 1976). This suggests that it could be used to fill bare spots left by a bunch grass such as ryegrass, yet it would not do so as rapidly as to preclude the occupation of such microsites by emerging pine seedlings.[1] Studies on coal mine spoils in Pennsylvania showed that 2-year survival or red pine in a red fescue sod was comparable to that afforded by other grass species recommended for reclamation.[2]

While grasses provide quick ground cover for erosion control, legumes can be very important in maintaining the long-term productivity of forest soils due to their role in N fixation (Haines and DeBell, 1979; Jorgensen, 1981). Legumes vary in their competitive aggressiveness, but with the exception of some species such as sericea lespedeza (Lespedeza cuneata (Dum.) G. Don.) which is extremely aggressive, most legumes used in reclamation do not pose such a serious competitive threat to pine seedlings as most grass species.

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[1] Parrish, D. 1982. Personal communication.

[2] Interim report by USDA-SCS, Plant Materials Center, Big Flats, New York.

Crownvetch (Coronilla varia L.) can be an aggressive competitor when fully developed. In a survey of 129 roadbank areas in Pennsylvania, Sharp and colleagues (1980) found that the number of woody species per 1000 m^2 decreased from 67.2 to 7.1 as the percent ground cover by crownvetch increased from 0 to > 85%. Crownvetch, however, is also very slow in developing from seed (Martin et al., 1976). Data on the relative establishment and growth rates in comparison with pines is lacking.

White clover (Trifolium repens L.) is not an aggressive competitor, and it tends to be eliminated from mixed stands in 2-3 years. Jones and coworkers (1975) reported significant decreases in the white clover fraction of total ground cover when Kentucky bluegrass (Poa pratensis L.) and red fescue were added to the reclamation mixture. In the same study, the percent ground cover by crownvetch was not decreased with the addition of a grass species. This lack of competitive aggressiveness by white clover may preclude any competition problems with emerging pine seedlings, but may also result in low N inputs over time.

Birdsfoot trefoil (Lotus corniculatus L.) is intermediate in its characteristics when compared to crownvetch and white clover. It is not an overly aggressive species (Martin et al., 1976), but is commonly used in reclamation seed

mixtures in southwest Virginia. Three and four year old stands of birdsfoot trefoil have been observed successfully competing against grasses such as tall fescue.

Besides careful selection and matching of grass and legume species, fertilizer levels can be manipulated to control competition.

The need for fertilization to establish pines on strip mined land is well established. Berry (1979) found that application of either fertilizer tablets or sewage sludge to loblolly pine growing on a Tennessee spoil increased seedling volume by 9- to 20- and 3- to 8-fold, respectively. But excessive fertilization, particularly with N, can lead to competition problems from exhuberant herbaceous growth. Duffy (1974) found that decreasing the initial N fertilization rate of a pine-grass plantation from 150 to 50 kg/ha significantly increased loblolly pine survival. Vogel (1980) also suggested that in pine plantations with grass competition problems only 50 kg N/ha should be applied at planting time.

The incorporation of legumes in a reclamation seeding mixture can be viewed as a low-level, constant source of N to insure proper spoil fertility without excessive herbaceous growth. Legumes generally need P fertilization to become established on mine spoils. Everett (1981) found

that growth of sericea lespedeza on two southwest Virginia mine spoils was maximized at fertilizer additions of about 90 kg P/ha. Mays and Bengtson (1974) similarly indicated the need for P fertilization of white clover stands grown on mine spoils. The need for K is not as well established. Everett (1981) suggested that K fertilization may actually interfere with P uptake. When more nutrient-demanding legumes such as alfalfa (Medicago sativa L.) are to be grown, however, K fertilization may be required (Mays and Bengtson, 1978).

Spoil characteristics

Spoil characteristics play a decisive role in determining the success of forest reclamation techniques. Among these characteristics, spoil acidity is of importance. Geidel (1979) has reviewed the chemistry of mine spoil acidity-alkalinity reactions. Iron-sulfide minerals present in the overburden oxidize to hydrous iron sulfates when exposed to a humid environment. Rainwater flowing over the weathered surfaces hydrolizes these salts and reduces the pH of the soil solution. Overburden may also contain calcareous material which may react with water to produce alkalinity at a rate limited by the partial pressure of CO2 in the soil atmosphere.

Literature is available on techniques that can ameliorate acid and alkaline spoils. Richardson and Farmer (1981) reported on the reclamation of acid copper/cobalt mine spoils in Idaho. Liming and fertilizing were necessary for satisfactory forage production. Because new spoils were being exposed to oxidation from erosive forces, they documented the need for continuous testing of spoil pH and liming over time. Similarly, Schramm (1966) described the reclamation of very acid spoils in Pennsylvania, while Einspahr and coworkers (1955) and Drake and Ririe (1981) studied acid mine spoil reclamation in the Midwest.

Alkaline (pH 8-9) materials were described by Weisenfluh and Ferm (1981) in a study of the geologic factors influencing the reclamation of coal spoils in Alabama. Grass and legume biomass production was maximized when NP fertilizer was applied. They reported As concentrations of 15 to 25 ppm on 35 different rock types, suggesting that toxicity problems may also be a factor in the reclamation of alkaline mine spoils.

In southwest Virginia, a mixture of sandstones and siltstones of different oxidation status compose most of the overburden (Howard, 1979). This results in much variability in the pH values of mine spoils. Daniels and Amos (1983), for example, found that the pH of the A horizon of five

different mine soils within a 135 ha area ranged from 3.6 to 6.5.

The physical characteristics of a spoil, and particularly texture, have also been reported as of importance. Plass (1974) found that the emergence of drill-seeded pine was restricted by fine-textured spoils. Daniels and Amos (1982) found that physical factors such as spoil compaction and surface crusting of fine-textured spoils were the major determinants of revegetation success.

Mycorrhizae

Root colonization by mycorrhizal symbionts is an important prerequisite for the reforestation of treeless areas (Mikola, 1969a, 1969b). When reforesting strip mined areas, inoculation of outplanted seedlings with a suitable symbiont is recommended (Marx, 1980; Ruehle, 1981).

Inoculation with PT is of importance when establishing pines on acid, low-fertility mine spoils. Marx and Artman (1979) showed that loblolly and shortleaf pine seedlings had higher survival, greater growth, and less metal toxicity when inoculated with PT than when inoculated with Thelephora terrestris, another mycorrhizal symbiont. The spoil pH in their study ranged from 3.4 to 4.6.

Walker and coworkers (1981) outplanted loblolly pine seedlings in Tennessee on a coal mine spoil with pH 6.0. Seedlings infected with PT had 32% greater survival than control seedlings. Height and root collar diameter were increased by 22 and 40%, respectively.

In a study conducted on coal spoils in Alabama and Tennessee, Berry (1982) reported that loblolly, pitch, and pitch x loblolly (Pinus rigitaeda) pine seedlings grew faster, and had lower concentrations of potentially toxic elements such as Mn, when inoculated with PT than with naturally occurring ectomycorrhizae.

There is some evidence, however, that PT may not always be the most appropiate symbiont. Schoenholtz (1983) grew PT-inoculated eastern white, Virginia, and loblolly pine seedlings on two southwest Virginia spoils with pH values ranging from 6.0 to 7.8. After one growing season, only loblolly pine seedlings showed a response to inoculation with increases in stem length and root collar diameter. The majority of the roots of all three species, however, were colonized with species other than PT.

Inoculation of pine seedlings with ectomycorrhizal symbionts is usually accomplished by the addition of mycelial inoculum to nursery beds or tree containers (Marx and Bryan, 1975). But this technique is probably not

feasible when reforestation is to be accomplished by direct seeding. Two inoculation alternatives that could be used with hydroseeding are the application of fungal basidiospores or pine litter.

Zarger and colleagues (1973b) suggested that pine established on mine spoils can become inoculated by windborne spores from surrounding stands. Robertson (1954) had previously demonstrated that Scotch pine seedlings can become infected when exposed to a "rain" of Boletus granulatus spores. It is not known, however, whether there is a correlation between the potential for infection and the time elapsed since disturbance. Freshly mined spoils may require inoculation, while spoils older than two or three years may have already been colonized by mycorrhizal symbionts.

Information on the practical feasibility of spore inoculation is scarce. Theodoru (1970) obtained 80% inoculation of Pinus radiata D. Don seedlings by inmersing the seeds in a water suspension of Rhizopogon luteolus spores. Marx (1976) and Marx and coworkers (1976) suggested that it was better to apply dry PT basidiospores because suspension in water seemed to decrease their effectiveness. But in a later study, Marx and coworkers (1979) found that PT basidiospores applied with a hydroseeder were more effective than spores dusted dry on the spoil surface.

The effects of spore inoculation of seeds, however, are far from being fully understood. Uncertainty exists on the conditions under which spores should be stored and the length of their viability (Mikola 1969a, 1969b). Shemakanova (1962) reports that several Russian researchers were successful in introducing mycorrhizae by inoculation with basidiospores, but he failed to reproduce those results.

Concerning the feasibility of using pine litter as a mycorrhizal inoculum, Bengtson and coworkers (1973) added pine litter from a forest floor to loblolly pine seedlings in a greenhouse experiment and observed an increase in their growth. They attributed this to a microbial, and possibly to a mycorrhizal, effect from the biota in the pine litter. They did not, however, quantify any mycorrhizal colonization differences in the seedlings.

Research is needed on the influence of soil fertility levels on the effectiveness of mycorrhizal colonization techniques. Marx and coworkers (1977) showed that high soil fertility levels decrease the susceptibility of pine roots to infection with PT. But Beckjord and colleagues (1980) found that northern red oak (Quercus rubra L.) seedlings fertilized with sodium nitrate and ammonium chloride had higher mycorrhizal infection levels than control seedlings.

MATERIALS AND METHODS

Greenhouse Study

Experimental design.

The treatments used in the greenhouse study included two spoil types (a grey siltstone and a brown sandstone), two fertilizer treatments (control, and 100 kg/ha each of N, P and K), and three mycorrhizal inoculation techniques (control, 56 kg/ha pine litter, and 250 g/ha PT basidiospores). The experimental design was factorial with three replications. The effects of these treatments on germination, survival, growth, and mycorrhizal infection of eastern white, Virginia, and loblolly pine were evaluated.

Spoil collection and characterization.

The spoils used in this study were a grey siltstone overlying the Clintwood coal seam, and a brown sandstone of the Marcum Hollow member, both within the Wise Formation. Both spoils were collected from active strip-mining operations, and were less than one year old. They were transported under cover to the Reynolds Homestead Research Center in Critz, Virginia. Nine samples from each spoil were

collected, air dried at room temperature, and sieved through a 2 mm screen. The fraction not passing the 2 mm screen was oven-dried at 105 C for 48 hrs and weighed as coarse fragments. Standard methods of analysis were used to measure particle size distribution (Day, 1965), soil pH (Mc Lean, 1982), total organic matter (Nelson and Sommers, 1982), and total N (Bremner and Mulvaney, 1982). Available P was determined colorimetrically using the ascorbic acid method following extraction with sodium bicarbonate (Olsen and Sommers, 1982). Total Mg, Ca, and K were determined by extraction with 1 N ammonium acetate adjusted to pH 7 and analyzed by atomic absorption spectrophotometry (Jackson, 1958).

Inoculum collection.

During late summer of 1981, PT basidiocarps were collected from a loblolly pine stand growing on an acid mine spoil in Buchanan County, Virginia. The mature portion of the basidiocarps was ground and passed through a 2 mm screen. Spores were stored in dark glass jars at 2 C. A beaker containing anhydrous calcium sulfate was placed inside each jar to reduce air moisture and prevent molding of the PT spores. Pine litter was collected from under a Virginia pine stand in Patrick County, Virginia, and ground to pass a 2 mm screen.

Treatments.

Pines were seeded in February 1982 in 0.10 m^2 flats containing either sandstone or siltstone. Forty seeds of white pine or 25 seeds of either loblolly or Virginia pine were hand-placed on the spoil surface. Mycorrhizal inoculation treatments were applied to the spoil surface as a slurry with 300 ml of water. After the flats were covered with 1 cm of Cellin hydromulch, a fertilizer solution prepared with KNO3, $(NH4)_2SO4$, and H3PO4 at rates described earlier was applied in 300 ml of water. Control plots received 300 ml of water for each treatment only. Flats were then sprayed with an additional 250 ml of water in order to leach the mulch and distribute the fertilizer salts. This treatment process was meant to create surface conditions similar to hydroseeded mine spoils.

Environmental conditions.

Seedlings were grown in the greenhouse with 16 hr photoperiods and a minimum night temperature of 16 C. Flats were watered daily to maintain spoil moisture at near field capacity. In late May 1982 the study was moved out of the greenhouse to avoid heat injury to the seedlings. Flats were placed on a plastic sheet adjacent to the greenhouse, and a bark mulch was placed between the flats. From this point, watering was applied only to supplement natural rainfall when deemed necessary.

Germination and growth.

Germination was measured 30 days after seeding by counting all germinated seedlings in each flat. Survival was determined by counting live seedlings in each flat after six months. At harvest, seedlings were washed free of spoil and cut at the root collar. Shoot and root biomass was estimated by drying the seedlings at 65 C for 72 hrs and weighing.

Mycorrhizal assay.

Inmediatedly after harvesting, each seedling root system was wrapped in a wet paper towel, enclosed in a plastic bag, and stored at 2 C. Trees were classified as either mycorrhizal or non-mycorrhizal. The degree of infection of mycorrhizal trees was categorized as low (1-33%), medium (34-66%), or high (67-100%) by spreading each root system on a white background and visually estimating the degree of infection under 10X magnification. Seedlings were also classified as being colonized with either PT, other mycorrhizae, or both.

Statistical analysis.

Statistical analyses were performed using Statistical Analysis System (SAS Institute, Inc., 1982). Means and standard errors were calculated for the spoil characterization data. Analyses of variance were performed using the statistical model outlined in Table A1 to test for

significant differences in germination and survival. The statistical model in Table A2 was used to test for significant differences in the percentage of colonized trees, degree of mycorrhizal infection, percentage of infection due to PT, shoot biomass, and root biomass. All the treatments were fixed effects. Arcsine transformation of all variables except shoot and root biomass were used in the analyses of variance. Duncan's Multiple Range Test was used to compare differences among means.

Field study

Experimental design.

A field study was conducted to test four nurse crops (a control, and 30 kg/ha each of perennial ryegrass and red fescue with 56 kg/ha of either crownvetch, common white clover, or birdsfoot trefoil), and three fertilizer treatments (a control, and either 60 or 120 kg N/ha with 70 kg P/ha and 60 kg K/ha), on ground cover, herbaceous vegetation height, pine establishment, and spoil erosion. The experiment was a 4 x 3 completely randomized design replicated three times. Plot size was 50 m^2.

Site characterization.

The study was installed in May 1982 on a site located at 82 39'W Longitude and 37 01'N Latitude on Route 620, 13 km E

of Norton, Virginia. The site had recently been recontoured after coal mining, but no revegetation had yet been attempted. The site had a southernly aspect with slopes ranging from 0 to 19%, and an elevation of approximatedly 700m. The spoil was characterized by taking one composite sample from three subsamples in each plot. Samples were then analyzed as described for the greenhouse experiment.

Daily rainfall was measured for 1982 at a site located 1.5 km North of the study area (Table A3). Wise County has one of the shortest growing seasons in Virginia, with just 157 days between the average date of the last frost in the Spring (May 5) and the average date of the last frost in the Fall (October 9).[3]

Treatments.

Based on preliminary pH determinations (Table A4), approximately 1.1 T/ha of agricultural limestone was applied and incorporated to a depth of 10 cm by disking, so as to raise the spoil pH to 5.5 and insure adequate legume establishment. In May 1983 fertilizer, grasses and legumes were applied with a hand-held centrifugal seeder. A mixture of eastern white, Virginia, and loblolly pine seeds was applied on all plots at 5 kg/ha for each species. The pine seed was applied in a water - Cellin hydromulch slurry (25

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[3] Climatological summary, No. 20-44, Wise, VA.

to 1 by weight) with the use of a 2300 l Bowie hydroseeder.

Vegetation assay.

In November, 1982, all live trees in each plot were counted. No attempt was made to differentiate among pine species. Ground cover was estimated by the line intercept method (Canfield, 1941), and herbaceous vegetation height was measured at 1 m intervals along the line intercepts.

Spoil erosion.

Spoil erosion from two treatments (control nurse crop with 120 kg N/ha, and birdsfoot trefoil with 60 kg N/ha) was evaluated with the use of sediment traps (Figure 1). These two treatments were selected to represent a past reclamation technique when only trees where planted, and there was little concern for the off-site impact of fertilizer runoff (the control nurse crop treatment), and a proposed future reclamation practice when trees may be grown with nurse crops under careful fertilizer management (the birdsfoot trefoil treatment). Each trap was a 4.5 x 11 m area delineated by plywood on three sides, and by Envirofence sediment cloth at the lower end. A grid consisting of three rows of steel rods across the slope was installed in the lower part of each trap. Spacing both between and within the rows was 33 cm, with the lowest row 16 cm uphill from the Envirofence. Rod height was measured at about 30 day

intervals for six months, and sediment volumes were estimated by utilyzing a computer program developed by the author (Table A5). Three bulk density samples were taken from each trap to estimate eroded sediment weight (Table A6). The trapping efficiency of the Envirofence cloth was tested by recording the weight of spoil that filtered through when 3 g were applied in 25 ml of water (Table A7).

Statistical analysis.

Statistical analyses were performed in a manner similar to that described for the greenhouse experiment. Analyses of variance were performed using the statistical model outlined in Table A8 to test for significant differences in ground cover, herbaceous vegetation height, and tree establishment. All the treatments were fixed effects. Arcsine transformation of ground cover was used in the analyses of variance. Duncan' Multiple Range Test was used to compare differences among means.

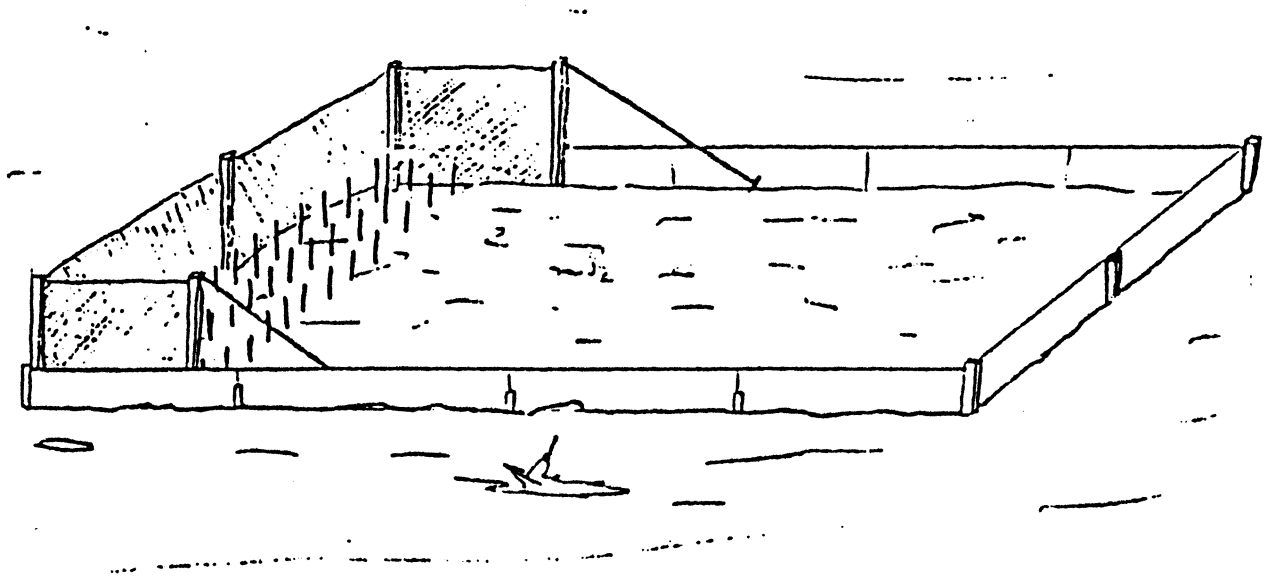


Figure 1. Sediment trap used to estimate spoil erosion in southwest Virginia.

RESULTS

Greenhouse Experiment

Spoil type characterization.

Physical and chemical characteristics of the two spoils used in this study are presented in Table 1 . The siltstone had 86% more coarse fragments than the sandstone, but a finer soil-size fraction. The soil solution reaction was alkaline (pH 7.4) in the siltstone, and acidic (pH 4.4) in the sandstone. Both organic matter and total N were four times greater in the siltstone. Sodium bicarbonate-extractable P levels were similar for both spoils, but cation levels were higher in the siltstone spoil.

Seedling performance.

Germination of all three species was significantly higher in the non-fertilized siltstone spoil, but survival was generally greater in the sandstone spoil (Table 2).

A significant interaction between spoil type and fertilizer treatment in the factorial analysis showed that fertilization affected pine germination and survival in a different fashion on siltstone than on sandstone spoil. A

Table 1. Selected physical and chemical properties of two mine spoils of the Wise Formation, Virginia.

Spoil Property	Grey Siltstone	Brown Sandstone
Coarse fragments (%)	65 ±2.67[1]	35 ±1.00
Sand (%)	16 ±0.25	53 ±0.57
Silt (%)	11 ±0.27	8 ±0.41
Clay (%)	8 ±0.00	4 ±0.20
pH	7.4 ±0.03	5.0 ±0.02
Organic matter (%)	0.9 ±0.02	0.2 ±0.01
N[2] (µM/g)	43.05 ±1.21	9.42 ±0.70
P[3] (µM/g)	0.14 ±0.01	0.19 ±0.01
K[4] (µM/g)	2.22 ±0.24	1.02 ±0.08
Ca (µM/g)	17.89 ±1.96	4.24 ±0.26
Mg (µM/g)	3.57 ±0.19	2.47 ±0.19

[1]Values are means ±S.E. of nine samples.

[2]Total Kjeldahl nitrogen.

[3]Sodium bicarbonate extraction.

[4]Cations were extracted with ammonium acetate.

Table 2. Germination (after 30 days) and survival (after six months) in a greenhouse as affected by spoil type and fertilization.

Spoil Type and Fertilizer	White Pine		Virginia Pine		Loblolly Pine	
	Germination	Survival	Germination	Survival	Germination	Survival
	- % -					
Siltstone						
None	12 a[1]	57 ab	55 a	95 a	34 a	87 a
Fertilized	7 ab	49 b	24 c	66 b	22 b	64 b
Sandstone						
None	4 b	85 a	38 b	100 a	16 b	95 a
Fertilized	6 b	75 ab	32 bc	91 a	16 b	92 a

[1]Values within columns followed by the same letter do not differ significantly at the 5% level by Duncan's Multiple Range Test.

one-way ANOVA of all spoil type and fertilizer treatment combinations showed that in siltstone, fertilizer significantly decreased Virginia and loblolly pine germination and survival with a non significant trend for white pine. When fertilized, Virginia pine germination and survival were decreased by 56 and 30%, respectively, while loblolly pine decreases were 35 and 26%. White pine germination and survival declined by 40 and 14%. On the other hand, the addition of fertilizer to the sandstone had little or no effect.

A significant interaction between spoil type and fertilizer treatment also showed a differential effect of fertilizer on stem and root biomass depending on the type of spoil (Table 3). Fertilized sandstone spoil significantly increased stem biomass of all three species. White, Virginia, and loblolly pine stem biomass was increased by 66, 890, and 696%, respectively, with the addition of fertilizer. Root biomass of Virginia and loblolly pine was also significantly increased (571 and 410%, respectively), with a similar trend for white pine (40%). But neither shoot nor root biomass was increased by fertilizer addition to the siltstone spoil.

The addition of mycorrhizal inoculum to the growth medium resulted in stem and root biomass changes that were species dependent (Table 4).

Table 3. Growth response of white, Virginia, and loblolly pine in a greenhouse as affected by spoil type and fertilization.

Spoil Type and Fertilizer	White Pine		Virginia Pine		Loblolly Pine	
	Stem Weight	Root Weight	Stem Weight	Root Weight	Stem Weight	Root Weight
	- - - - - - - - - - - - - - - - mg - - - - - - - - - - - - - - - -					
Siltstone						
None	61 a[1]	37 a	64 a	37 a	147 a	51 a
Fertilized	66 a	40 a	91 a	43 a	180 a	76 a
Sandstone						
None	122 a	100 b	93 a	75 a	274 a	172 a
Fertilized	203 b	140 b	920 b	503 b	2182 b	877 b

[1]Values within columns followed by the same letter do not differ significantly at the 5% level by Duncan's Multiple Range Test.

Table 4. Stem and root biomass of white, Virginia, and loblolly pine in a greenhouse as affected by mycorrhizal inoculation treatments.

Inoculation Treatment	White Pine		Virginia Pine		Loblolly Pine	
	Stem Biomass[1]	Root Biomass	Stem Biomass	Root Biomass	Stem Biomass	Root Biomass
	mg					
Control	84[2]	60 a	253 a	132 a	877 a	407 a
Pine litter	79	64 a	298 a	179 a	672 a	239 a
Pisolithus tictorius spores	182	117 b	362 a	204 a	689 a	294 a

[1]A spoil x inoculation treatment interaction was significant at the 5% level.

[2]Values within columns followed by the same letter do not differ significantly at the 5% level by Duncan's Multiple Range Test.

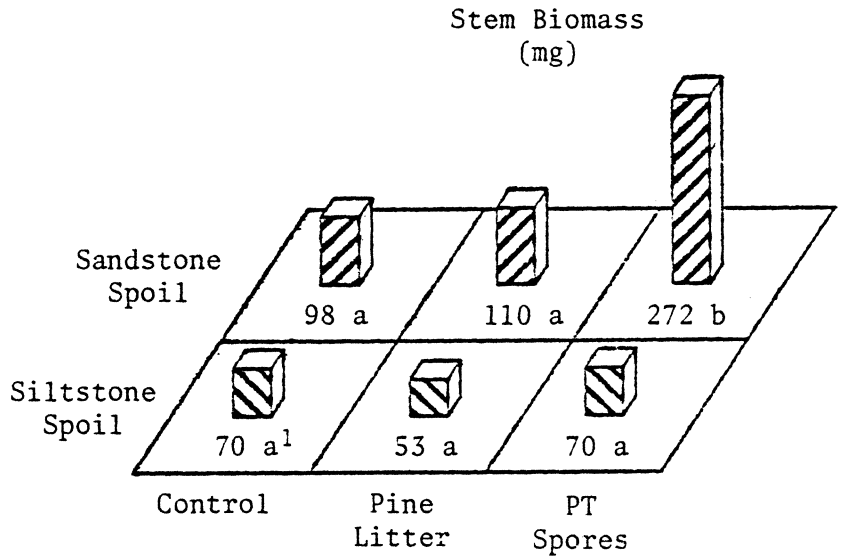
Pine-litter addition did not result in a significant change in stem and root biomass in any species. Virginia pine showed a trend towards an increase in biomass, while the opposite was true for loblolly pine.

The PT-spore treatment did not significantly change stem or root biomass in either Virginia or loblolly pine. Root weight of white pine, however, was significantly increased over the controls. Stem weight of white pine showed a differential response to the application of PT spores: seedlings grown in sandstone and inoculated with PT had significantly higher stem biomass than those growing in any other environment (Figure 2).

The analyses of variance also showed that fertilizer efficiency in increasing stem and root biomass was not affected by mycorrhizal inoculation, since the interactions between fertilizer treatments and mycorrhizal inoculation techniques were nonsignificant.

Mycorrhizal colonization.

The extent of mycorrhizal colonization as affected by inoculation treatment was greater in sandstone spoil than in siltstone spoil (Table 5). In siltstone spoil, no significant differences between inoculated and control seedlings were observed in either the frequency of mycorrhizal trees, the degree of root infection, or the symbiont species composition of the root systems.



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[1]Means not followed by the same letter are significantly different at the 0.05 level.

Figure 2. Effects of spoil type and inoculation treatments on white pine seedling stem biomass.

Table 5. Mycorrhizal colonization of white, Virginia, and loblolly pine in a greenhouse as affected by spoil type and inoculation treatment.

Spoil Type and Inoculation Treatment	White Pine			Virginia Pine			Loblolly Pine		
	Colonized Trees[1]	Degree of Infection[2]	Incidence of PT[3]	Colonized Trees	Degree of Infection	Incidence of PT	Colonized Trees	Degree of Infection	Incidence of PT
Siltstone									
None	0 a[4]	0 a	0 a	2 a	1 a	0 a	8 a	1 a	0 a
Pine litter	0 a	0 a	0 a	20 a	1 a	0 a	20 a	13 a	0 a
Pisolithus tinctorius spores	0 a	0 a	0 a	4 a	1 a	0 a	21 a	9 a	0 a
Sandstone									
None	60 b	22 ab	8 a	65 b	25 b	18 a	95 b	74 b	36 ab
Pine litter	33 ab	16 a	50 ab	92 c	48 c	26 a	100 b	79 b	23 ab
Pisolithus tinctorius spores	50 b	30 b	60 b	98 c	50 c	81 b	94 b	75 b	67 b

[1]Colonized trees (number of mycorrhizal trees/total number of trees) x 100.

[2]Degree of infection = (number of mycorrhizal roots/total number of roots) x 100.

[3]Incidence of PT = (number of trees with PT/number of mycorrhizal trees) x 100

[4]Values within columns followed by the same letter do not differ significantly at the 5% level by Duncan's Multiple Range Test.

In the sandstone, even control seedlings had a significantly higher percentage of colonized trees than either the control or inoculated seedlings growing in siltstone spoil. Addition of either pine litter or PT spores did not increase the percent of colonized trees in white or loblolly pine. In Virginia pine, however, the addition of either form of inoculum significantly increased the number of colonized trees over the controls. Pine litter increased the percent of colonized trees by 41%, while the addition of PT spores resulted in a 51% increase.

The degree of infection of colonized trees in the sandstone spoil was significantly increased by 92 and 100%, respectively, with the addition of either pine litter or PT spores in Virginia pine, but the two forms of inoculum were not different in their infectiveness. White and loblolly pine did not show a significant increase in their degree of infection as a result of mycorrhizal inoculation.

The addition of PT spores resulted in a significant increase in the percentage of PT-infected roots in Virginia pine as compared to control seedlings (350%) or seedlings inoculated with pine litter (211%). White pine roots had a significantly higher percent of PT infection in the PT spores treatment when compared to the controls. The 650% increase in the degree of PT infection for this treatment

was not significantly different, however, to the 525% obtained with the application of pine litter. In loblolly pine, PT root infection was also highest in the PT-spores treatment, but differences with the pine litter and control seedlings were nonsignificant.

Mycorrhizal colonization was not affected by differential responses to fertilizer application, since the analyses of variance showed that interactions between fertilizer treatments and inoculation techniques were nonsignificant.

Field Study

Spoil characterization.

Edaphic characteristics of the study site are presented in Table 6 . Compared to the spoils used in the greenhouse study (Table 1), this spoil had an average percentage of coarse fragments (54%). Its loam-textured soil-size fraction had a strongly acidic soil reaction (pH 4.4). Organic matter, total N, and sodium bicarbonate extractable P levels were relatively high, while cation levels were intermediate with respect to either the siltstone or sandstone spoils.

Effect of nurse crops.

The addition of a nurse crop significantly increased ground cover in the study area (Table 7). Control nurse crop plots were colonized to some degree by naturally

Table 6. Selected physical and chemical properties of a mine spoil of the Wise Formation, Virginia.

Spoil Property	Level
Coarse fragments (%)	54 ±1.26[1]
Sand (%)	20 ±0.48
Silt (%)	15 ±0.32
Clay (%)	11 ±0.39
pH	4.4 ±0.04
Organic matter (%)	1.5 ±0.11
[2]N (µM/g)	54.14 ±1.65
[3]P (µM/g)	0.22 ±0.02
[4]K (µM/g)	1.72 ±0.09
Ca (µM/g)	10.20 ±1.13
Mg (µM/g)	2.47 ±0.87

[1]Values are means ±S.E. of 26 samples.

[2]Total Kjeldahl nitrogen.

[3]Sodium bicarbonate extraction.

[4]Cations were extracted with ammonium acetate.

occurring species of grasses and forbs. Birdsfoot trefoil had the highest amount of ground cover (65%), followed by white clover (52%) and crownvetch (44%). The increased ground cover obtained by birsfoot trefoil was significantly different from crownvetch but not from white clover.

Herbaceous-vegetation height was not significantly different for white clover (13.9 cm) and birdsfoot trefoil (13.4 cm) when compared to the controls. Crownvetch, however, had significantly less height growth (9.5 cm) than species in the other three treatments.

A trend was evident which showed a reduction in pine establishment with the addition of a nurse crop. Although differences with the controls were non significant, the presence of a nurse crop reduced pine establishment by at least 51%. Among nurse crops differences in pine establishment were non significant, with the highest rate of pine establishment being observed with white clover (6,586 trees/ha), followed by birdsfoot trefoil (6,180 trees/ha), and crownvetch (5,835 trees/ha).

None of the crops evaluated met the 75% ground cover requirement of present Virginia reclamation law (Division of Mined Land Reclamation, 1979) when averaged over all fertilizer treatments. Certain crop-fertilizer treatment combinations, however, did meet this minimum standard as presented later.

Table 7. Ground cover, herbaceous vegetation height, and pine establishment as affected by nurse crop treatment after one growing season in southwest Virginia.

Nurse Crop[1]	Ground Cover	Herbaceous Vegetation Height	Pine Establishment
	(%)	(cm)	(trees/ha)
Control	24 a[2]	14.4 a	13,563 a
White clover	52 bc	13.9 a	6,586 a
Birdsfoot trefoil	65 c	13.4 a	6,180 a
Crownvetch	44 b	9.5 b	5,835 a

[1]The same mixture of perennial ryegrass and red fescue was sown with each of the legume nurse-crops.

[2]Values within columns not followed by the same letter are significantly different at the 5% level by Duncan's Multiple Range Test.

Fertilizer effects.

Addition of a fertilizer mixture significantly increased ground cover over the controls (Table 8). Ground cover was increased by 211 and 255% with the addition of 60 or 120 kg N/ha, respectively, but there was no significant difference in ground cover between the two fertilizer treatments.

Herbaceous vegetation height was also significantly increased with fertilizer addition when compared to the controls. Height increases of 78 and 187% were observed with the addition of 60 and 120 kg N/ha, respectively. In this case, however, the additional increase in height obtained with the high N treatment was significant when compared to the low N treatment.

Differences in pine establishment between fertilized and control plots were non significant, but addition of fertilizer did decrease pine establishment by at least 49% when compared to the controls.

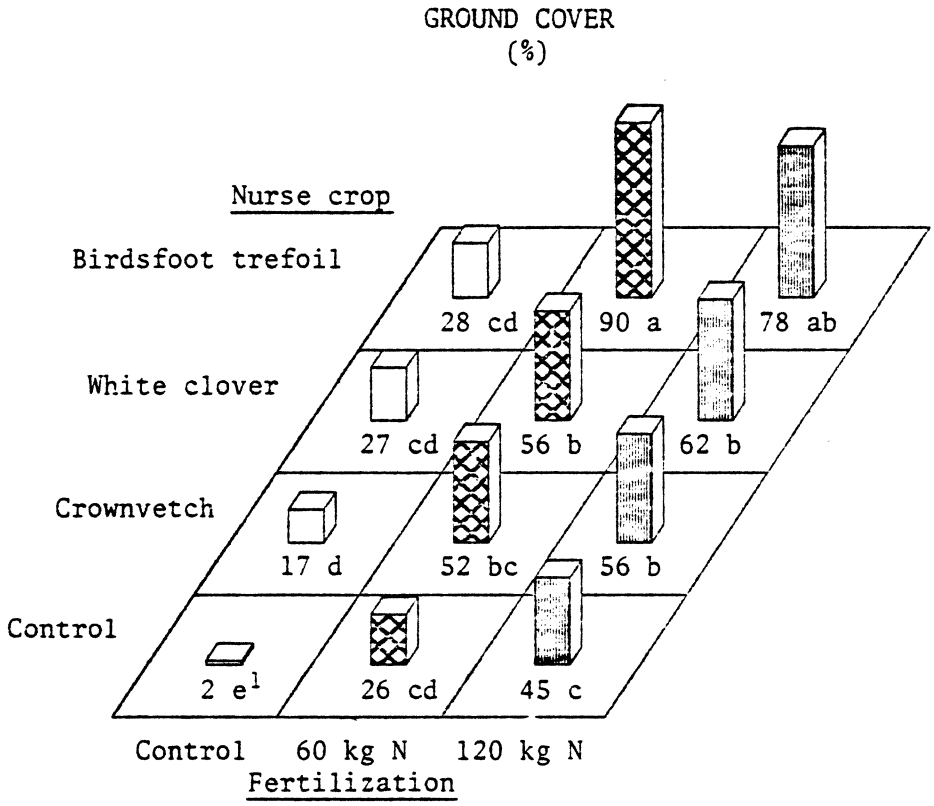
Nurse crop and fertilizer combinations.

At each fertilizer level, addition of a nurse crop significantly increased ground cover over the control plots, except for crownvetch at 60 kg N/ha which was not significantly different from the control (Figure 3). Within each nurse crop, addition of fertilizer significantly increased ground cover over the unfertilized plots.

Table 8. Ground cover, herbaceous vegetation height, and pine establishment as affected by fertilizer treatment after one growing season in southwest Virginia.

Fertilizer Treatment	Ground Cover	Herbaceous Vegetation Height	Pine Establishment
	(%)	(cm)	(trees/ha)
None	18 a[1]	6.8 a	12,455 a
60 kg N/ha	56 b	12.1 b	5,313 a
120 kg N/ha	64 b	19.5 c	6,355 a

[1]Values within columns followed by the same letter do not differ significantly at the 5% level by Duncan's Multiple Range Test.



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[1]Means not followed by the same letter are significantly different at the 0.05 level.

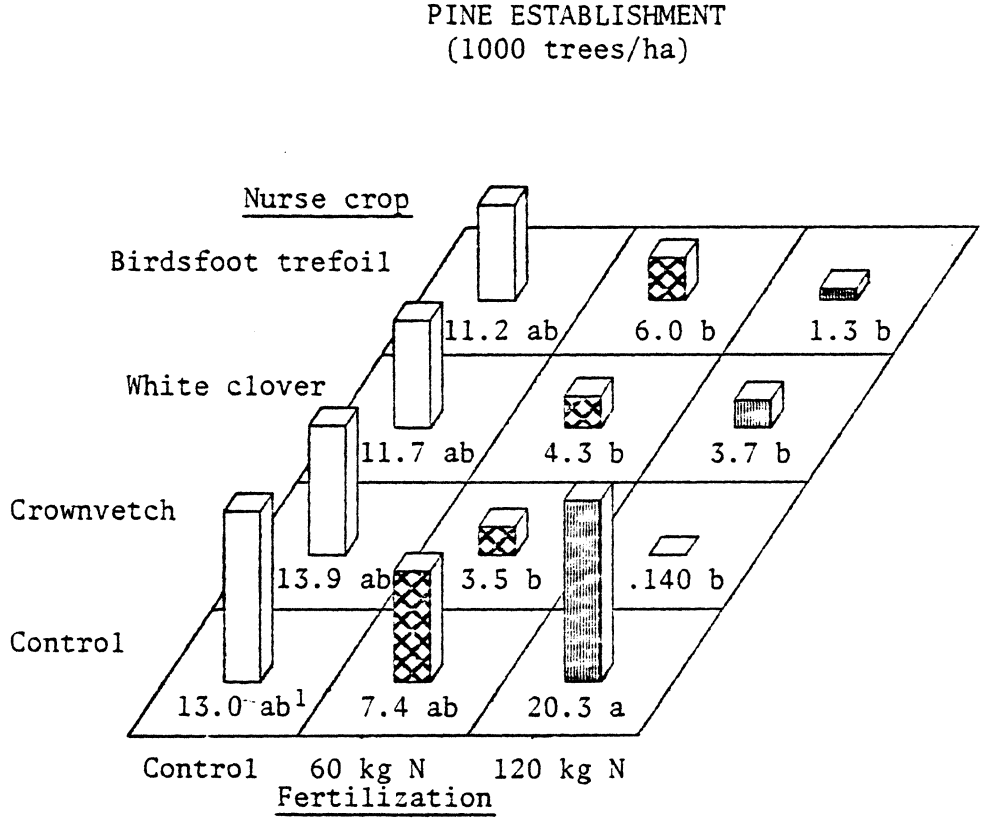
Figure 3. Ground cover as affected by nurse crop and added N after one growing season in southwest Virginia.

Only birdsfoot trefoil at both levels of N met the minimum 75% ground cover required by present reclamation law. Birdsfoot trefoil at 120 kg N/ha, however, was not significantly different from the other treatment combinations where both a nurse crop and a fertilizer were used.

Within each of the grass-legume combinations tested, pine establishment values showed a decreasing trend with increasing amounts of N applied (Figure 4). Although these differences were not significant, the highest number of trees was found in the unfertilized plots, and the lowest number of trees in the plots receiving 120 kg N/ha.

Differences in pine establishment between the control and seeded plots were non-significant where no fertilizer or 60 kg N/ha were applied. At 120 kg N/ha, however, addition of a nurse crop significantly decreased pine establishment.

Among plots that received both a herbaceous crop and fertilizer, differences in pine establishment were non significant. Birdsfoot trefoil at 60 kg N/ha, however, had the highest pine establishment values (6,000 trees/ha), followed by white clover at 60 (4,300 trees/ha) and 120 (3,700 trees/ha) kg N/ha.



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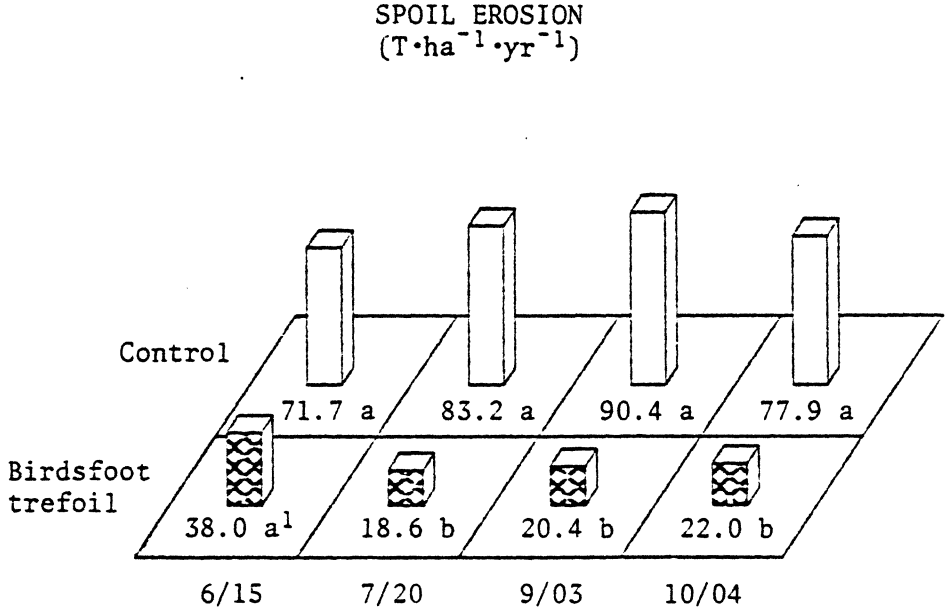
[1]Means not followed by the same letter are significantly different at the 0.05 level. Values are combined totals for three species.

Figure 4. Pine establishment as affected by nurse crop and added N after one growing season in southwest Virginia.

Spoil Erosion.

The use of birdsfoot trefoil as a nurse crop decreased spoil erosion during the first growing season (Figure 5). At four different measurement dates, erosion in the birdsfoot trefoil plots was reduced by 47, 78, 77, and 72% over the controls. The latter three measurements represented a significant decrease in spoil erosion.

The tradeoff between ground cover and pine establishment is shown in Figure 6 . Plots with birdsfoot trefoil experienced a 50% increase in ground cover, and about a four-fold decrease in erosion. Pine establishment, however, was decreased by about 70%.



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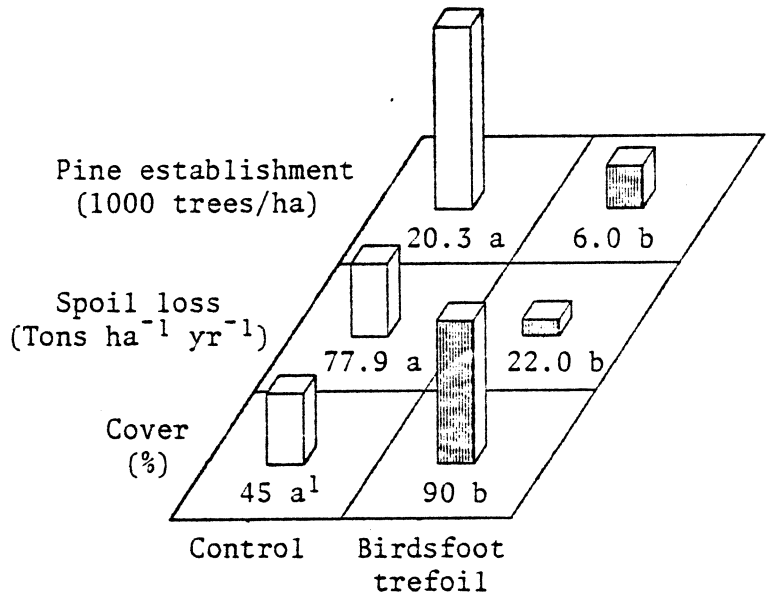
[1]Means within columns not followed by the same letter are significantly different at the 0.05 level.

Figure 5. Spoil erosion as affected by the addition of birdsfoot trefoil after one growing season in southwest Virginia.



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[1]Means within rows not followed by the same letter are significantly different at the 0.05 level.

Figure 6. Ground cover, spoil loss, and pine establishment as affected by the addition of birdsfoot trefoil after one growing season in southwest Virginia.

DISCUSSION

Greenhouse Experiment

Spoil Characterization.

The amount of coarse fragments present in the siltstone spoil (65%) was higher than that found in the sandstone spoil (35%) (Table 1). Wide differences in the coarse fragment content of mine spoils within the Appalachian region are documented. Plass and Vogel (1973) found that the coarse fragment content of 10 West Virginia mine spoils ranged from 58.2 to 67.1%, with an average of 62.8%, while Daniels and Amos (1982) reported coarse fragment contents of 34.5 to 45%, with an average of 40.8%, in southwest Virginia. Because pine seedlings in this experiment were grown within the volume afforded by each flat, the higher percentage of coarse fragments in the siltstone spoil reduced the total rooting volume available to the trees as compared to the sandstone spoil.

The sandstone spoil had a coarser soil-size fraction than the siltstone spoil (Table 1). The sand fraction in the sandstone (53%) was more than three times that found in the

siltstone (16%). Particle size distributions reported by authors for field studies in the region are intermediate between those of the two spoils used in this experiment. Schoenholtz and Burger (1983) reported sand fractions of 12 and 29% for two mine spoils in southwest Virginia. In the same region Daniels and Amos (1982) reported sand contents of 31 to 40%. Because fine-textured soils restrict soil aeration (Spurr and Barnes, 1980) and tend to form surface crusts (Daniels and Amos, 1982), the fine-textured siltstone spoil created a low-aeration, high-moisture environment. These physical characteristics of the siltstone spoil suggested the existance of a medium unfavorable for root development.

The pH values of the siltstone (7.4) and sandstone (5.0) spoils were similar to those reported for other spoils of the Wise formation in southwest Virginia, which showed that alkaline as well as acid spoils exist in the region. Daniels and Amos (1983) found that soil acidity ranged from pH 3.6 to 6.5 in the A horizon of five mine spoils.

The higher pH value of the grey siltstone may have reflected the absence of oxidized pyrite or other acid-forming minerals, whereas the brown sandstone showed evidence of aerobic weathering and oxidative pedogenesis. The resulting pH difference between both spoils may have

nutrient availability implications over time, since the availability to plants of chemical elements changes with pH. Although they provide an estimate of plant available levels, the amounts of P, K, Ca, and Mg reported in Table 1 were obtained with the use of buffered solutions, and could thus be different in an unbuffered pH environment.

The organic matter content (0.9%) and total N (43.05 M/g) of the siltstone spoil were more in agreement with values reported in other studies than those of the sandstone spoil (0.2% organic matter and 9.42 μM/g total N). Daniels and Amos (1983) reported organic matter contents of 0.6 to 2.8%, with an average of 1.5%, in southwest Virginia mine spoils. Schoenholtz (1983) found total N levels of 55.9 and 51.1 μM/g for two sites in the same area. The large difference in total N levels between the two spoils used in this study can be attributed to the strong positive correlation between organic matter and total soil N that exists in most soils (Stevenson, 1982).

Levels of P, K, and Ca in the siltstone (0.14, 2.22, and 17.89 μM/g, respectively) and sandstone (0.19, 1.02, and 4.24 μM/g, respectively) spoils were similar to those reported for other mine spoils of the Wise Formation (Daniels and Amos, 1982; Schoenholtz and Burger, 1983). Magnesium levels were somewhat lower than expected, perhaps

because the young age of these spoils did not allow for sufficient weathering of Mg-containing minerals. Differences in the levels of P, K, Ca, and Mg between the two spoils can be attributed to the inherent properties of the parent material, particularly in such young soils. Even on mine spoils of up to 12 years of age levels of Ca, and to some extent K and Mg, have been found to vary little with changes in organic matter content (Daniels and Amos, 1982).

Seedling performance.

Low germination values (Table 2) reflected the extreme sensitivity of the pine seeds at the spoil-mulch interface to moisture conditions. Since smaller particle sizes have a higher surface to volume ratio, and thus higher water holding capacity than coarser materials, the siltstone spoil held more water for longer periods of time than the sandstone spoil. The higher water holding capacity associated with the siltstone spoil provided a moisture environment at the spoil-mulch interface which was more favorable for pine germination. The lack of significant differences in germination between fertilized and unfertilized sandstone further suggests moisture as the limiting factor.

Lower survival in the siltstone spoil could be attributed to its higher water-holding capacity. Seedlings growing in

this spoil experienced severe damping-off; and these flats were observed to have higher moisture than those flats containing sandstone spoil. These high moisture conditions may have been conducive to microbial and fungal growth, which may have caused the damping-off.

The lower survival values in the fertilized siltstone could also be attributed to the negatively synergistic effect of spoil type and fertilizer treatment. Fertilizer addition may have enhanced the microbial environment by introducing nutrients that could be used by dampening-off fungi, and may also have promoted the formation of surface crusts by the spoil microflora. This assumption is supported by the results of a greenhouse study by Bengtson and coworkers (1973) where surface crusts of about 1.75 cm in depth were observed when pine was grown in fertilized spoil. They suggest that fertilizer salts may have adversely affected pine survival by releasing free ammonia into the spoil. Bengtson and coworkers (1973) found statistically significant differences in pine establishment between unfertilized pots and pots fertilized with N compounds that yielded ammonia upon hydrolysis, even when applied at only 50 kg N/ha. The $(NH4)_2SO4$ fertilizer used in this study is likely to have released ammonia, particularly at the high pH (7.4) level of the siltstone spoil.

The data in Table 3 suggest that a combination of physical and chemical factors limited pine growth on these spoils. The finer texture of the siltstone spoil, with its increase in soil moisture and resulting decrease in aeration, its tendency to form surface crusts, and its higher coarse fragment content which resulted in lower total rooting volume combined to restrict pine growth in this spoil.

The sandstone spoil provided a coarser-textured growth medium with better aeration and percolation characteristics. When nutrients were applied to offset its lower natural fertility, the combination of favorable physical and chemical factors resulted in pine growth that was significantly greater than that of any other spoil type and fertilizer treatment combination. In the sandstone, the favorable physical condition of the growth medium precluded the development of conditions limiting nutrient uptake by the pines.

The differential response of pine species to mycorrhizal inoculation (Table 4) could be explained in terms of their adaptability to mine spoils. Virginia pine is recognized as one of the best pine species for direct seeding on mine spoils due to its ability to tolerate a wide range of soil reaction and moisture conditions (US Soil Conservation

Service, 1978). Loblolly pine is not as well adapted to stressful environments as Virginia pine, but it still grows well on a wide range of mine-spoil types (Vogel, 1981). White pine is even more site-specific in terms of available moisture, and it does not tolerate low pH levels as well as Virginia pine (US Soil Conservation Service, 1978). This suggests that pine species that are not well adapted to a harsh environment may benefit more from colonization by adapted symbionts than hardier species.

Mycorrhizal colonization.

The differences in mycorrhizal colonization between the two spoils (Table 5) can be attributed to the edaphic characteristics shown in Table 1. Since PT has been found to be well adapted to acid spoils (Schramm, 1966), it is not surprising that it was absent in the alkaline siltstone spoil. The data suggest that in a particular edaphic environment, a symbiont that is not well adapted will fail to colonize tree roots regardless of the intensity of the inoculation treatment.

The finer texture of the siltstone spoil resulted in higher moisture content and lower porosity and aeration than in the sandstone spoil. Since mycorrhizae are obligate anaerobes and low oxygen tensions tend to restrict mycelial development (Pritchett, 1979), the most probable explanation

for the poor mycorrhizal development in the siltstone spoil is the effect of texture on soil aeration.

Since both pine litter and PT spores were applied on the spoil surface, the texture of the two mine spoils used in this experiment may also have influenced the rate at which the mycorrhizal inoculum was translocated to the tree roots. Surface crusting and low porosity in the siltstone spoil may have prevented the inoculum from reaching the rhizosphere of the pine seedlings. In the sandstone spoil, on the other hand, the presence of a coarse growing medium favored the downward translocation of the inoculum by mass flow, and increased the chances of a spore germinating in the vicinity of a host root.

In the sandstone spoil, physical and chemical limitations of mycorrhizal growth were less apparent. In the absence of serious edaphic limiting factors, it was possible to observe a species-dependent response to mycorrhizal inoculation treatments. Virginia pine was the species that responded most favorably to mycorrhizal inoculation. Both inoculation with pine litter and PT spores increased the percentage of colonized trees and the degree of root infection, suggesting sandstone was the more favorable medium for root colonization.

The use of pine litter as a mycorrhizal inoculum was meant to introduce a broad range of fungal symbionts to the rhizosphere in the hope that a well-adapted species would be present to colonize the root system of the pine seedlings. With the addition of PT spores, however, a specific symbiont was introduced as an inoculum to infect the root system. The significant response of Virginia pine to this inoculum as reflected by the increase in the percentage of PT-infected roots, suggests that its value as a stress-resistant species is further enhanced by its ease of infection.

White and loblolly pine did not respond as clearly to mycorrhizal inoculation, since the number of colonized trees and their degree of infection was not significantly increased over the controls (Table 5). The low germination and survival of white pine (Table 2), and the slow intial growth of this species (US Forest Service, 1965), precluded the adequate analysis of mycorrhizal colonization. Since no attempt was made to prevent natural inoculation, the lack of response to PT inoculation in loblolly pine could be attributed to the high levels of colonized trees (95%), degree of infection (74%), and incidence of PT (36%) in the uninoculated sandstone flats (Table 5).

White pine seedlings growing in sandstone and inoculated with PT spores, however, showed both an increase in the percentage of PT-infected roots and in stem biomass (Figure 1). This suggests that even under limiting environmental conditions, site-demanding tree species can benefit from colonization by an adapted symbiont.

Field Study

Spoil Characterization.

Compared to values reported for other spoils in the Wise Formation (Daniels and Amos, 1983; Schoenholtz and Burger, 1983), the spoil used in this study (Table 6) had a higher percentage of coarse fragments (54%) and a lower pH (4.4). It is unlikely that either of these spoil properties restricted tree growth. In the field, tree seedlings had a large rooting volume to explore in a deep, recontoured mine spoil. Although strongly acid, soil acidity should not have limited pine growth, especially after liming. Magnesium content (2.47 μM/g) was below that expected. Schoenholtz and Burger (1983) reported Mg levels of 18.0 and 10.6 μM/g in two spoils of Wise County, Virginia. Characterizations of the mine spoils in the Wise Formation (Daniels and Amos, 1982, 1983) have not disclosed Mg deficiencies. The difference in Mg content between that found in this study

and those reported in the literature are probably not important for pine growth. Texture, N, P, K, and Ca were in agreement with values reported by these authors.

Effect of nurse crops.

The increase in ground cover associated with the use of a nurse crop (53, 63, and 45% for white clover, birdsfoot trefoil, and crownvetch, respectively) (Table 7) confirms the need for such crops when pine plantations are to be established on reclaimed land. Differences in ground cover by nurse crops can be explained in terms of their different growth habits as previously mentioned. The slower initial growth of crownvetch may delay the appereance of a dense stand until two to three years after seeding (Martin et al., 1976); therefore, it is possible that this crop will show an increase in ground cover in subsequent growing seasons.

The decrease in herbaceous height of crownvetch as compared to the other crops could be similarly attributed to its slower development rate, or to a different competitive strategy. As the different plant species used in this study competed for site resources, crownvetch did not respond to competition pressure by increasing its height growth, but rather by establishing a sufficiently strong root system to insure adequate survival.

Pine establishment values (13,563, 6,586, 6,180, and 5,835 trees/ha for control, white clover, birdsfoot trefoil, and crownvetch, respectively) compare well with previously established minimum levels of survival. In a study in southwest Virginia were pine seeds were broadcast-seeded from a helicopter, Zarger and colleagues (1973a) defined an "acceptable" stand as one consisting of at least 1500 seedlings/ha.

Reductions in the number of seedlings with the use of a nurse crop (51, 54, and 57% for white clover, birdsfoot trefoil, and crownvetch, respectively) agree with other studies which showed the negative impact of herbaceous vegetation on young tree plantations (Vogel and Berg, 1973; Duffy, 1974).

In this study, the use of white clover, birdsfoot trefoil, and crownvetch represents a gradient of increasing competitive aggressiveness. The data on pine establishment in Table 7 seems to parallel this gradient. Research by Kramer and coworkers (1952) and Schoenholtz and Burger (1983) indicates that these decreases in pine establishment must be attributed to competition for light between the emerging pine seedlings and the herbaceous vegetation.

While differences in pine establishment among nurse crop combinations have to be attributed to the effect of the

legume crops (since both perennial ryegrass and red fescue were used with each legume), differences with the controls should be attributed to the combined effect of the grass and legume species. Although the grass species used in this experiment were selected due to their low growth form and minimal competitive aggressiveness (Vogel, 1981), they undoubtedly also provided some competition for light resources.

An additional explanation for the negative effect of herbaceous vegetation on pine establishment is in the possible existance of an allelopathic effect. Pine seedlings have been shown to be susceptible to allelopathic compounds. Priester and Pennington (1978) reported on the inhibitory effect of broomsedge (Andropogon virginicus L.) on the growth of young loblolly pine. Rietveld (1975) showed that ponderosa pine (Pinus ponderosa Laws.) germination and radicle growth were affected by compounds secreted from various grass species. Among the nurse crop species used in this study, root leachates of both perennial ryegrass and fescue have been shown to decrease the growth of some hardwood tree species (Fales and Wakefield, 1981). Although the allelopathic relations between the particular herbaceous and tree species used in this study have not been investigated, the literature reviewed suggests that an

allelopathic effect may have hindered pine establishment in addition to reduced light.

Fertilizer effects.

The failure of the high N treatment to further increase ground cover over the low N treatment (Table 8) suggests that above 60 kg N/ha other nutrients or edaphic factors become limiting. This agrees with research by Duffy (1974) and Vogel (1980) which suggested that applications of 50 kg N/ha are sufficient to maintain adequate herbaceous cover in pine plantations.

While ground cover is one of the competition factors restricting pine growth, it is also one of the objectives to be achieved as prescribed by present reclamation law (Division of Mined Land Reclamation, 1979). Herbaceous vegetation height is also a limiting factor on pine growth, yet no minimum nurse-crop height requirements are specified in reclamation guidelines. When viewed in this context, the increased height (61%) of the herbaceous vegetation achieved with the high N treatment must be considered as a negative result in terms of forest reclamation objectives. This suggests that application rates above 60 kg N/ha for pine-grass-legume establishment should be discouraged.

The pine establishment levels obtained with the addition of a fertilizer mixture (5,713 and 6,355 trees/ha with 60

and 120 kg N/ha, respectively) are still well above the minimum number of seedlings (1,500 trees/ha) as defined in previous research by Zarger and coworkers (1973a). These establishment values will undoubtedly become smaller in subsequent growing seasons. The larger number of trees present in the control plots will provide additional assurance that a mature stand will be established. It is possible, however, that the smaller number of stems in the fertilized plots may result in a stand with more optimal mean annual growth. This is because a smaller number of trees may make more efficient use of the site resources. In the southeastern US, for example, young loblolly pine maximize wood production at stocking levels of approximatedly 2,800 trees/ha (US Forest Service, 1965).

Nurse crop and fertilizer combinations.

The data in Figure 3 indicate that a grass-legume nurse crop combination of medium competitive aggressiveness, as exemplified by the birdsfoot trefoil treatment in this experiment, can provide optimal ground cover (90%) at levels of N that need not exceed 60 kg/ha.

Data in Figure 4 further suggest that when pine plantations are to be established on mine spoils, the use of a nurse crop of medium competitive aggressiveness, such as that used in the birdsfoot trefoil treatment in conjunction

with N fertilization levels of no more than 60 kg/ha, results in tree stocking levels (6,000 trees/ha) that are adequate for present reclamation objectives.

Spoil Erosion.

The erosion data in Figure 5 confirm that ground cover provides erosion control benefits (47, 78, 77, and 75% less erosion than the controls) that persist over time. The results indicate that mine reclamation managers can expect a four-fold decrease in erosion with the use of a nurse crop if conditions are similar to those of this experiment. Whether such reductions are of importance to them will depend on the legal and social framework within which they have to operate. The amount of erosion recorded where a nurse crop was used (22 T ha^{-1} yr^{-1}), however, was similar to values reported for cultivated fields in the southeastern US (24 T ha^{-1} yr^{-1}) (Lull and Reinhart, 1972) and the average rate of man-made erosion in the US (20 T ha^{-1} yr^{-1}) (Schumm and Harvey, 1982). When compared to the average rate of natural erosion in the US (10 T ha^{-1} yr^{-1}) (Schumm and Harvey, 1982), and erosion from a mature pine plantation in the southeastern US (0.02 T ha^{-1} yr^{-1}) (Lull and Reinhart, 1972), the rate of erosion observed in this experiment when a nurse crop was not used (77.9 T ha^{-1} yr^{-1}) is likely to be above "acceptable" erosion limits.

The data in Figure 5 serve as a reference for those who have to define "acceptable" spoil erosion values. If 75% continues to be the minimum ground cover standard required for successful reclamation, then environmental managers should be aware that erosion of over 20 tons ha^{-1} yr^{-1} is likely to occur during the first six months after mining on sites similar to the one used in this experiment.

The results in Figure 5 further suggest that 20 T ha^{-1} yr^{-1} is probably the minimum amount of erosion to be expected from recontoured strip mines over the first six months. It is likely that even with 100% ground cover after six months 20 T ha-1 yr-1 should be expected under these conditions.

Among the factors to be considered in this ground cover versus erosion tradeoff is the effect of ground cover on pine establishment (Figure 6). Although it is too early to decide whether the number of seedlings found in the birdsfoot trefoil plots is sufficient to insure an adequate stand, previous research by Zarger and colleagues (1973a) suggests that the present establishment values are more than adequate to meet forest regeneration objectives.

SUMMARY AND CONCLUSIONS

The different physical and chemical characteristics of the spoils used in the greenhouse experiment influenced the germination, survival, mycorrhizal colonization, and growth of the tree seedlings.

The higher water-holding capacity of the siltstone spoil was probably responsible for the increase in germination (in the absence of fertilizer) observed in this spoil. Survival, however, was higher in the sandstone spoil. This could be a result of better aeration and drainage, and lower coarse fragment content of this spoil.

The more favorable physical characteristics of the sandstone spoil also resulted in an increase in growth. When nutrients were applied to offset its lower inherent fertility, the combination of favorable physical and chemical factors resulted in pine growth that was significantly greater than that of any other spoil type and fertilizer combination.

Mycorrhizal colonization as a response to inoculation varied by spoil type and pine species. No colonization response was observed in the siltstone spoil, probably due

to the absence of symbionts adapted to its alkaline soil reaction. In the sandstone, Virginia pine responded most favorably to the introduction of PT by spore inoculation. White pine, however, was the only species to show a growth response to PT inoculation.

In the field experiment, use of a nurse crop significantly increased ground cover over the control plots, confirming that herbaceous vegetation can effectively increase site protection in tree plantations. But the presence of herbaceous vegetation also resulted in a decrease in pine establishment of at least 51%.

Addition of 60 kg N/ha significantly increased ground cover and the height of the herbaceous vegetation over the controls. Addition of 120 kg N/ha further increased nurse crop height but not ground cover, suggesting that 60 kg N/ha was sufficient to insure adequate ground cover. Pine establishment was also decreased by at least 49% when fertilizer was applied.

The only nurse crop to obtain the minimum 75% ground cover required by law was birdsfoot trefoil, which did best in terms of both ground cover (90%) and pine establishment (6,000 trees/ha) at 60 kg N/ha, suggesting that this nurse-crop fertilizer combination should be considered for operational reclamation use.

Three months after establishment, the use of a nurse crop significantly reduced erosion over the controls. The persistence of this reduction in erosion over the length of the growing season indicates that mine reclamation managers can expect four-fold reductions in spoil erosion with the use of a nurse crop.

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APPENDICES

Table A1. Main effects, interactions, and error term used for germination and survival hypothesis testing.

Source		df
SPC		2
SPL		1
FRT		1
MYC		2
SPC X SPL		2
SPC X FRT		2
SPC X MYC		4
SPL X FRT		1
SPL X MYC		2
FRT X MYC		2
SPC X SPL X FRT		2
SPC X SPL X MYC		4
SPC X FRT X MYC		4
SPL X FRT X MYC		2
SPC X SPL X FRT X MYC		4
	MODEL	35
	ERROR	72
	TOTAL	107

SPC= Species SPL= Spoil FRT= Fertilizer MYC= Mycorrhizae

Table A2. Main effects, interactions, and error term used for % colonized trees, degree of infection, incidence of PT, shoot biomass, and root biomass hypothesis testing.

Source	df
SPL	1
FRT	1
MYC	2
SPL X FRT	1
SPL X MYC	2
FRT X MYC	2
SPL X FRT X MYC	2
MODEL	11
ERROR	24
TOTAL	36

SPL= Spoil FRT= Fertilizer MYC= Mycorrhizae

Table A3. Rainfall for Wise County, Virginia, Jan-Dec 1982, as measured approximatedly 13 km E of Norton.

Month	Rainfall (mm)
Jan	119
Feb	168
Mar	100
Apr	22
May	43
Jun	61
Jul	66
Aug	163
Sep	164
Oct	70
Nov	141
Dec	60
Total	1,177

Table A4. Preliminary pH values and pH in Adams-Evans buffer (pH 7.95) for field study spoil.

pH in water	pH in Adams-Evans buffer
4.2	6.42
4.1	6.48
4.3	6.44
4.5	6.51
4.4	6.62
---	----
$\bar{x}$= 4.3	$\bar{x}$=6.49
std. dev.=0.16	std. dev.=0.08

Table A5. SEDTRAP Computer System.

```
//B0438REP JOB 322B0,MINE
/*KEY XXXXXXX
/*PRIORITY STANDARD
/*JOBPARM LINES=8
/*ROUTE PRINT VM2.MINE
//STEP1 EXEC SAS
//SYSIN DD *
*****************************************************************
* WELCOME TO SEDTRAP, A COMPUTER SYSTEM DESIGNED TO CALCULATE*
* SOIL EROSION VALUES FROM READING THE DECREASING HEIGHT      *
* OF MARKERS INSTALLED AT THE BOTTOM OF SEDIMENT TRAP PLOTS. *
* THIS PROGRAM WAS DESIGNED BY RICARDO E. PREVE, 228 CHEATHAM*
* HALL, VIRGINIA TECH, BLACKSBURG, 24061. COPYRIGHT PENDING. *
*****************************************************************
*
* WE NAME THE DATA SET TO BE USED
*
DATA NORTON;
*
* THE INPUT STATEMENT SPECIFIES THAT THE COVER (CONTROL OR
* BIRDSFOOT TREFOIL) INFORMATION IS IN COLUMN 1, ROW POSITION
* OF THE ROD MEASURED IN COLS 2-3, COLUMN POSITION IN COLS
* 4-5, REP IN COL 6, THE BASE RECORDED HEIGHT MEASUREMENT IN
* COLS 50-53 (IN THIS CASE 10/30), AND THE LATEST HEIGHT
* MEASUREMENT IN COLS 60-63 (IN THIS CASE 2/23).
*
INPUT COVER 1 ROW 2-3 COL 4-5 REP 6 HTF 50-53 HTL 60-63;
*
*WE OBTAIN THE SPOIL VOLUME IN CM3;
*
V=91.44*457.2*(HTF-HTL);
*
*BULK DENSITY OF THE SEDIMENT IS 1.17 G/CM3;
*
W=V*1.17;
*
*WE CHANGE GRAMS TO METRIC TONS;
*
W=W/1000000;
*
*TRANSLATE TO HECTARE BASIS;
*
WHA=W/.0041806;
*
*ASSUMING 114 DAYS OR 0.312 YEARS;
*
WHAY=WHA/0.312;
*
```

```
*WE MAKE AN ALLOWANCE FOR THE 87% CLOTH EFFICIENCY;
*
WHAY=WHAY/0.87;
*
* WE LABEL THE TOP OF EACH DATA COLUMN WITH A MEASUREMENT DATE
*
************  5/26 6/04 6/15 6/22 7/20 9/03 10/410/30 1/07 2/23;
*
* WE INFORM THE PROCESSOR THAT DATA FOLLOWS IN CARD FORMAT
*
CARDS;
*
*
* Rod heights in cm are entered here
*
*
* WE CALL ON THE GLM-SAS PROCEDURE
*
PROC GLM;
*
* WE SPECIFY THAT TYPE OF COVER IS HOW WE CLASSIFY THE DATA
*
CLASSES COVER;
*
* WE DEFINE THE ANALYSIS MODEL
*
MODEL WHAY = COVER;
*
* WE REQUEST THAT MEANS BE SEPARATED USING DUNCAN'S
* MULTIPLE RANGE TEST
*
MEANS COVER / DUNCAN;
*
* FORMAT IS PRINTED FOLLOWING STANDARD SAS PROCEDURES
*
```

Table A6. Bulk density of eroded sediment.

Trap 1	1.29	Trap 4	0.97
	1.26		1.14
	1.45		0.84
Trap 2	1.08	Trap 5	0.99
	1.21		1.25
	1.29		1.28
Trap 3	1.02	Trap 6	1.24
	1.13		1.37
	1.21		1.14

$\bar{x}$=1.17
std. dev.=0.15

Table A7. Efficiency of Envirofence sediment cloth in retaining 3 g of spoil applied in 25 ml of water.

Spoil filtered through (g)	% retained
0.42	86
0.14	95
0.18	94
0.21	93
0.11	96
0.28	91
0.35	88
0.71	76
0.68	77
0.36	88
0.70	77
0.66	78
$\bar{x}$=0.40	$\bar{x}$=87
std.dev.=0.23	

Table A8. Main effects, interactions, and error term used for ground cover, herbaceous vegetation height, and pine establishment hypothesis testing.

Source	df
Nurse Crop	3
Fertilizer	2
Nurse Crop X Fertilizer	6
MODEL	11
ERROR	24
TOTAL	35

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