MINESOIL FACTORS INFLUENCING THE PRODUCTIVITY OF NEW FORESTS ON RECLAIMED SURFACE MINES IN SOUTHWESTERN VIRGINIA [1/]

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Abstract.— Coal companies and regulatory agencies have not been totally cognizant of the establishment requirements and long-term nature of forest trees that will ultimately cover 70-90% of the reclaimed land in Virginia and parts of adjoining states. Reclamation and revegetation guidelines primarily emphasize site conditions and establishment techniques for herbaceous ground cover rather than conditions and requirements for woody plant species. Several research projects in southwestern Virginia show that reclamation for trees requires minesoil construction techniques that often differ from those used for the establishment of hayland/pasture. Overburden type and minesoil depth dramaticslly affect tree growth and wood production. An overburden placement study was established to investigate the effects of various mixtures of sandstone and siltstone overburden on the growth of pitch x loblolly pine (Pinus xrigitaeda) seedlings. After 4 years, trees in sandstone minesoils had more than five times the stem volume than trees in siltstone minesoils (685 cm^3 vs 123 cm^3). A highly significant linear relationship (R^2=.91) existed between stem volume and percent sandstone in the overburden mixture. In this study sandstone-derived minesoils were better for tree growth because they have a lower pH, lower levels of soluble salts, and fewer coarse fragments than siltstone-derived minesoils. A study to determine which minesoil properties influenced the growth of 8-year-old white pines (Pinus strobus L.), ranging in height from 0.9 m to 6.9 m, revealed that minesoil depth to a restrictive layer and soluble salt levels were the two most important factor affecting tree performance.

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INTRODUCTION

Most reclaimed surface mines in the Appalachians will ultimately return to forest land, either as the result of planned reforestation efforts, or through natural succession on "hayland" and "pasture land" abandoned after bond release. During the first four to five years following the inception of PL 95-87, "hayland/pastureland" was the dominant post-mining land use permitted. The extra expense of planting trees discouraged most operators from designating managed or unmanaged forest land as post-mining land uses. More recently, however, a combination of incentives and disincentives caused operators to switch to unmanaged forest land either because 1) state regulations required pasturing or hay harvests prior to bond release; 2) repairs needed to maintain the ground cover were more costly in the long run than tree planting; or 3) landowners were interested in the productive potential of forest crops. The primary concern of most coal companies is obtaining immediate ground cover and achieving adequate tree survival for bond release. The long-term productivity of these new forests is, at most, a secondary concern of operators, but it should be a primary concern of landowners.

The establishment of "unmanaged forest land" generally requires the same reclamation and revegetation techniques used to establish hayland/ pasture, with the additional step of planting about 1,000 to 1,500 trees/ha. The predominant crop tree species for reclamation in Virginia is white pine (Pinus strobus L.), which is usually planted along with various nitrogen-fixing tree and shrub species such as black locust (Robinia psuedoacacia L.), autumn olive (Elaeagnus umbellata L.), and bicolor lespedeza (Lespedeza bicolor Turcz).

To date, most research conducted in the eastern U.S. has shown that prime farmland can be returned to crop production and that most minesoils can be used for pasture. Until recently, however, little work has been done to demonstrate the productive potential of forest crops on minesoils. Given the large acreage now being planted to trees, technical information was needed for reclamation guidelines that would ensure productive sites for forest crops. To meet this need, a comprehensive research program was begun in 1980 by the Forestry Department at Virginia Polytechnic Institute and State University with initial funding by the Powell River Project.[3/] The purpose of this paper is to summarize results from several studies that identified minesoil factors that directly influence forest productivity.

[3/] The Powell River Project, initiated by the Penn Virginia Resources Corporation, is a consortium of industry, several universities and colleges in Virginia, and various State and Federal agencies, and supports research devoted to enhancing the productive land-use of surface mined land and the general welfare of citizens in the coal-mining counties of Virginia and surrounding states.

EFFECT OF OVERBURDEN SELECTION ON TREE GROWTH

Coal seams in the Virginia Appalachians and surrounding states are generally overlain by overburden strata of sandstone and siltstone. These layers of rock are blasted and removed during the mining process and must be replaced during reclamation. Native soils are often shallow and steep making it difficult for coal operators to stockpile and replace these soils during reclamation. Consequently, "topsoil substitute" variances are frequently issued when coal operators can demonstrate that overburden materials would be as productive as native topsoil.

Sandstone and siltstone differ in their physical and chemical characteristics. These differences can affect revegetation success. In a preliminary greenhouse study at Virginia Tech, Preve et al. (1984) found that a sandstone mine spoil was a better growth medium than a siltstone spoil for pine (Pinus spp.) seedlings. The sandstone overburden had fewer coarse fragments, better aeration porosity, and lower levels of soluble salts. The effects of overburden type on tree growth was further studied in the field. A rock mix study was established to compare the effects of various sandstone/siltstone overburden mixtures on the growth of pitch x lohlolly pine hybrid (Pinus xrigitaeda) seedlings.

Study Methods

The study plots were constructed during the winter of 1982 on a previously mined flat bench in Wise County, Va. The study consisted of four replications of five overburden mixes: pure sandstone (SS), pure siltstone (SiS), 2:1 SS:SiS, 1:1 SS:SiS, and 1:2 SS:SiS. Overburden from an adjacent mining operation involving the Taggart and Taggart Marker coal seams of the Marcum Hollow member of the Upper Wise Formation was used. The strata were chosen for this study because of their known low sulfur content and relatively high carbonate content. Sandstone and siltstone overburden were stockpiled separately. The spoils were mixed in the required ratios and placed in the center of 3- by 6-m plots. After all spoil mixtures were in place, each pile was graded flat with a small (D-4) bulldozer, taking care to minimize compaction. After grading, the area was level with a spoil depth of 1.2 m over a highly compacted underlying bench.

The entire study area was fertilized with 1,120 kg/ha of 15-30-15 granular fertilizer, consisting of ammonium nitrate, diammonium phosphate, and potassium chloride. During May 1982, all plots were mulched with straw (2300 kg/ha) and hydroseeded with a slurry containing Kentucky-31 tall fescue (Festuca arundinacea Schreb., selection Ky-31) and wood fiber mulch (840 kg/ha).

The pine seedlings were grown in Spencer-Lamaire root trainers (Hillson model, 150 cc/cavity) for 16 wk prior to planting in the study plots. In April 1983 half of each plot was broadcast sprayed with a 2% glyphosate solution to kill the ground cover, and containerized pine seedlings were planted on a 0.75- by 0.75-m spacing within the sprayed area. Seedlings were planted with a 21 g slow-release fertilizer pellet (20-10-15).

After three growing seasons, a composite soil sample was collected from each plot. Soil samples were taken by collecting all soil within two 30- by 30-cm areas, randomly located within each plot, to a depth of 20 cm, and compositing these samples for analysis. Tree growth was measured after the fourth season.

Results

Overburden samples were analyzed for coarse fragment content, particle size distribution of the soil fraction (particle size < 2mm), and percent moisture retention at 3, 5, and 15 bars using a pressure membrane extractor (table 1). Coarse fragment content was high in all rock mixes, but was highest in the siltstone plots (74%). Coarse fragment content in siltstone plots was significantly greater than the sandstone plots (52%). Within the soil fraction, there were significant differences in the amount of sand and silt between treatments, but no relationship between rock-mix and clay content was observed. Despite these differences in sand and silt content, the textural class of all soils was a sandy loam. Moisture retention was highest in the siltstone plots and decreased proportionally as sandstone was added. When the value for the 5 bar water content was multiplied by percent soil to estimate the total amount of water available for trees, total moisture was significantly greater in the sandstone plots (30 g/kg vs 20 g/kg), because these plots had almost twice as much soil (48% vs 26%).

Table 1. Minesoil physical properties as affected by rock type.

Rock Mix	Coarse Fragment Content	Particle Size			Moisture Retention		
		sand	silt	clay	3 bars	5 bars	15 bars
	- - - - - - - % - - - - - - - - -				- - - - - g / kg - - -		
Sandstone	52 b [1/]	74 a	15 d	11	69	62 b	31
2:1 mix	57 ab	71 ab	18 c	11	70	64 b	39
1:1 mix	64 ab	68 bc	20 b	12	71	68 ab	37
1:2 mix	63 a	64 c	23 ab	13	80	71 ab	35
Siltstone	74 a	57 d	29 a	14	86	78 a	40

1/ Values within a column followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 0.05 level of significance

Chemical analyses included pH, electrical conductivity (EC) of a 1:5 soil:water extract, total Kjeldahl nitrogen (N), and ammonium acetate-extractable phosphorus (P), potassium (K), calcium (CA), and magnesium (Mg) (table 2). Overburden mix was significantly related to pH, EC, N, K, Ca, and Mg, but not P. Soluble salts (as indicated by EC), pH, and nutrients were highest in the siltstone plots and lowest in the sandstone plots. The pH ranged from 7.9 (siltstone) to 6.9 (sandstone), which is high compared to many minesoils, and higher than levels considered ideal for pines (pH 5.0-5.5). Cementing carbonates weather to produce high pH and salt levels during the first few years after placement. Electrical conductivity followed the same trend as pH, and both variables were highly correlated with each other ($P = .0001$; $r = -.87$).

Table 2. Minesoil chemical properties as affected by rock type.

Rock Mix	pH	EC	Total N	NH_4OAC-Exchangeable Nutrients			
				P	K	Ca	Mg
		dS/m	g/kg	- - - - - - - ug/kg - - - - -			
Sandstone	6.9 c [1/]	0.4 d	0.7 c	47 a	49 c	435 d	162 b
2:1 mix	7.1 bc	0.7 c	0.9 bc	56 a	62 b	548 c	206 a
1:1 mix	7.3 bc	0.7 c	0.9 bc	53 a	60 b	562 c	215 a
1:2 mix	7.5 ab	0.9 b	1.0 ab	51 a	63 b	666 b	220 a
Siltstone	7.9 a	1.3 a	1.6 a	42 a	73 a	777 a	227 a

1/ Values within a column followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 0.05 level of significance

Tree growth was greatly affected by rock mix (table 3). Tree height, diameter, and volume increased as the amount of sandstone increased in the rock mix. A linear relationship between tree volume and percent sandstone in the rock mix was highly significant ($P = .0108$; $R2 = .91$). Trees in pure sandstone plots had over five times more stem volume than trees in siltstone plots.

Since this study involved only two specific overburden strata from a localized region, these results cannot be extrapolated to all sandstone and siltstone overburdens. The study does, however, demonstrate the over-riding influence that overburden characteristics can have on tree growth, and it provides justification for suggesting that the best overburden material be placed at the surface.

Table 3. Effect of rock mix on hybrid pine growth after 4 years.

Rock Mix	Tree Growth		
	Height	Diameter	Volume [1/]
	- cm -	- mm -	- cm^3 -
Sandstone	146.2 a [2/]	40.4 a	685 a
2:1 mix	141.4 ab	37.8 ab	621 ab
1:1 mix	111.4 bc	30.8 b	338 bc
1:2 mix	111.5 bc	30.6 b	337 bc
Siltstone	84.8 c	21.8 c	123 c

1/ Volume = $1/3 \times 3.14 \times (\text{diameter}/2)^2 \times$ Height.
2/ Values within a column followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 0.05 level.

EFFECT OF MINESOIL DEPTH ON TREE GROWTH

Another study was conducted to determine which minesoil factors were influencing the growth of white pines that had been growing for 8 yrs on a series of reclaimed benches in southwestern Virginia. Thirty-four white pines were systematically selected to cover a range of tree sizes and obvious minesoil/site properties (surface soil color, parent material, presence or absence of ground cover, etc.). Individual trees were selected for this study if their size was representative of all immediately surrounding trees. This selection process increased the likelihood that growth performance reflected site conditions.

Study Methods

A 1-meter-deep backhoe pit was dug at the base of each tree, and a taxonomic soil description was obtained from each pit with special emphasis given to identifying restrictive layers of rock or traffic pans that would impede root growth. Clods collected from these layers had bulk densities of at least 1.7 g/cm^3. Other minesoil physical properties analyzed were surface soil (0-10 cm) bulk density, coarse fragment content, and particle size distribution of the soil fraction. Routine chemical analyses performed on the surface soil included pH, EC of a 1:5 soil/water extract, sodium bicarbonate-extractable P, ammonium acetate-extractable K, Ca, and Mg, total Kjeldahl N, and anaerobic mineralizable N.

Results

Correlations between minesoil variables and total tree height are presented in table 4. Depth to a restrictive layer, EC, and extractable K and Mg were correlated with growth ($P<0.1$). Rooting volume index (rooting depth x percent soil fraction) was the most highly significant variable in this study, accounting for almost 50% of the variation in tree height. Minesoil nutrient levels were not correlated with growth, indicating that, on these sites, minesoil fertility was not as influential as minesoil physical properties on tree growth. This was further substantiated by foliar analyses which showed no relationship between pine needle tissue concentrations and tree performance.

Tree height ranged from 0.9 m to 6.9 m and averaged 2.5 m. To estimate the effect that these differences might have had at the time of tree harvest, white pine site index (SI_{50}) was estimated at the location of each tree (from total height) with Beck's (1971) equation for site index. Site index ranged from approximately 10 m to 36 m with an average of 25 m.

Site index was plotted as a function of the square root of rooting depth (fig. 1). Although there is a considerable scatter of points along the regression line, it is evident that rooting depth can have a strong effect on site quality. According to Doolittle (1958), the average site quality for white pine in the Southern Appalachians is approximately 24 m. The regression equation developed from this study indicated that a site index of 24 corresponded to a rooting depth of approximately 75 cm. No tree with a site index of 24 m or greater was found on minesoil depths of less than 30 cm. These data suggest that better-than-average growth for the Southern Appalachians can be achieved if at least 75 cm of nontoxic minesoil is left at the surface in an uncompacted state.

Table 4. Correlations of selected minesoil properties with the height of thirty-four 8-year-old white pines growing on reclaimed benches in Wise Co., Va.

Minesoil Property	Significance	R-value
Depth to a restrictive layer (cm)	.0003	.58
Soil-sized fraction (%)	ns[1/]	—
Rooting Volume Index[2/]	.0001	.71
Sand (%)	ns	—
Clay (%)	ns	—
Bulk density (g/cm^3)	ns	—
pH	ns	—
Electrical conductivity (dS/m)	.0090	-.43
Organic matter (%)	ns	—
Total soil N (%)	ns	—
Anaerobic mineralizable N (ppm)	ns	—
Extractable P[3/] (ppm)	ns	—
Extractable K[4/] (ppm)	.1050	-.29
Extractable Ca (ppm)	ns	—
Extractable Mg (ppm)	.0560	-.33

1/ indicates that minesoil variables are not significantly correlated with tree height at a significance level of 0.1 or greater.
2/ Rooting Volume Index = Depth x soil-sized fraction.
3/ Sodium bicarbonate extractable P.
4/ Ammonium acetate extractable cations.

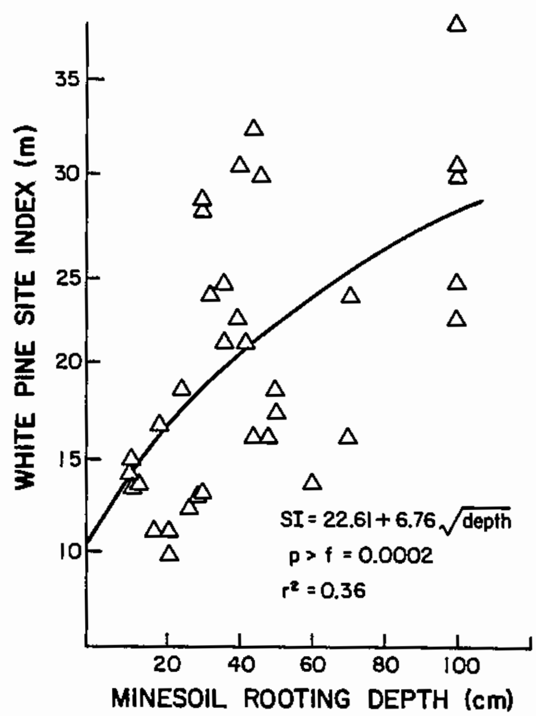

Figure 1. Relationship between projected site index and minesoil depth to a restrictive layer, for thirty-four 8-year-old white pines on reclaimed benches in Southwest Va.

SUMMARY AND CONCLUSIONS

These studies demonstrate the importance of minesoil physical properties on tree growth, and the impact that overburden selection and placement can have on these properties. This research agrees with the findings of Ashby et al. (1984) who reported excellent growth of black walnut, yellow-poplar, and white oak on 30-year-old minesoils. They stated that excellent tree growth can occur when trees are planted in deep, nontoxic minesoil, and are maintained free of competing vegetation. The largest trees in these Virginia studies were white pines growing in minesoils derived from brown sandstone. Brown sandstones originate from near the surface and are more oxidized compared to the deeper, gray sandstones. Brown sandstone usually has a lower pH, lower levels of soluble salts, and produces fewer coarse fragments than minesoils derived from gray sandstone or siltstone. Minesoils derived from this material are often deep and well-drained with a pH of 4.5 to 5.5 which is ideal for pines. Although the high level of oxidized iron can fix large quantities of P applied as fertilizer, trees are capable of utilizing fixed P due to the presence of mycorrhizal fungi that symbiotically colonize tree roots after a year or two (Schoenholtz et al., 1987). Results from these studies, as well as subjective evaluations of numerous pine plantings throughout the coal mining region of Virginia and surrounding states, suggest that non-pyritic, brown sandstone is the best topsoil substitute for tree establishment and growth.

Brown sandstone is often placed beneath the surface because the pH and P availability are too low to support the lush growth of grasses and legumes which are traditionally used for reclamation. Consequently, the potential long-term productivity of many sites that will ultimately become forest land is being sacrificed for the short-term perceived need of a lush dense herbaceous ground cover. These studies illustrate the need for landowners, coal companies, and regulatory agencies to evaluate overburden materials and placement techniques in light of the differnt site and soil requirements of the intended post-mining vegetation.

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