Effects of Minesoil Properties on Young White Pine (Pinus strobus) Height Growth[1]

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Abstract: Seventy-eight fixed area plots located in 5 to 9-year-old white pine (Pinus strobus) plantations on reclaimed mine soils in Virginia and West Virginia were selected to evaluate the effects of minesoil properties on tree growth. A pit 1-m deep was dug at the base of one representative tree on each plot to determine rooting depth and physical and chemical properties of the subsurface horizons. Surface soil samples (0-15 cm) were also collected for analysis of selected chemical and physical properties. In addition, plot information including tree species, number of trees, percent cover, percent slope, position on slope, aspect, overburden type and elevation was also collected. Multiple regression analysis was used to model the effects of mine soil properties on white pine tree growth. Results indicate that the properties most correlated with tree growth were rooting volume, defined as the volume of soil to a restrictive layer, slope percent and phosphorus content. A linear regression equation for white pine height growth was developed using rooting depth, P content, slope and Mn content.

In 1977, the U.S. Congress enacted PL 95-87 (The Surface Mining Control and Reclamation Act) which requires mine operators to reclaim strip mines. Two major requirements of this law are to i) return the land to the approximate original contour and ii) revegetate, with subsequent productivity equalling or exceeding premining conditions.

Prior to mining, the Eastern Coal Region of the U.S. was predominantly forested. Conversion from premined forested conditions to hayland/pastureland, a higher order land use allowable under the provisions of PL 95-87 (USDOI/OSM, 1988), is desirable in most areas in order to diversify the economic base (Zipper, 1986). However, most of the hayland/pastureland has gone unused for its intended purpose because it is often located in remote areas on land that is too steep to permit use of agricultural equipment.

Forestland, as a designated post-mining use, is gaining in popularity in Virginia and West Virginia. In Virginia,

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the Division of Mine Land Reclamation estimates that 80 to 85% of all reclaimed land is in forest use. Eastern white pine (Pinus strobus), which occurs naturally throughout the mountains of Virginia and West Virginia, is frequently planted. It competes well with herbaceous cover due to its ability to survive in areas of limited light. Eastern white pine is found on many different sites, including such extremes as dry rock ridges and very wet areas, although best development occurs on moist sandy loams (Harlow et al., 1978). Because white pine is site sensitive, a wide range of growth is found on reclaimed mines. Under optimal conditions, white pine can produce large sawtimber harvestable in 35 to 40 year rotations (Balmer and Williston, 1983). By identifying growth limiting factors in minesoils, coal companies and regulatory agencies can ensure that proper reclamation practices are employed to promote good tree growth. The purpose of this study was to identify these factors by examining the relationships between selected minesoil properties and growth of 5-year-old white pine.

Methods

This study was located on a series of reclaimed Appalachian coal fields in Wise County, VA and Mercer, Wyoming and McDowell Counties in West Virginia (Figure 1). Appalachian coal fields cover approximately 72,000 square miles in parts of nine states, extending from Pennsylvania to Alabama. The coal seams of Appalachia are of Pennsylvanian age with the most abundant coal-bearing rock types being the fine-grained siltstones and shales (Vogel, 1980). Most sites have a thin layer of soil typically classified as Typic Dystrochrept. The predominant natural vegetation in Appalachia is the mixed hardwood forest. Nonforested lands are in agricultural land uses, mostly pastureland.

Seventy-eight sites, on fourteen different mines in Virginia and West Virginia, were chosen to include a wide range of tree growth and site conditions. At each of the reclaimed mines, plots no smaller than 0.02 ha (202.5 sq. m) and no larger than 0.04 ha (405 sq. m) were established. The selected plots were located in 5 to 9 year old white pine plantations.

Aboveground properties measured at each plot included slope percent, aspect, slope position, and distance and direction to the closest natural forest stand. Two soil sampling points were located on each plot. At each of these locations, surface horizon bulk density was also measured using the excavation method as described by Blake (1965). To estimate functional rooting depth, a cone penetrometer was used. At twenty-five locations, randomly located along a diagonal line across the plot, the penetrometer had a force of 300 psi applied. When the desired pressure was achieved, a depth reading was taken.

A pit, 1 meter deep, was dug at the center of each plot

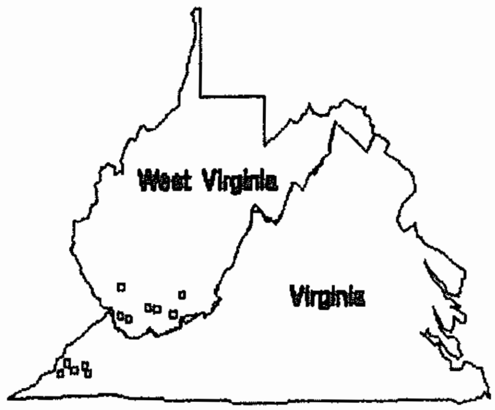

Figure 1. White pine study plots.

near the base of a representative tree. The selected tree exhibited no signs of suppression or damage. In each pit, a taxonomic profile description was completed. Descriptors included depth of each horizon, color, texture, structure, consistence, and depth to mottles. Soil samples were collected from each of the delineated horizons. Also, from each horizon, two soil clods were obtained to determine sub-surface bulk density (Blake, 1965).

Soil depth was measured as the depth to solid rock or to a traffic pan. A rooting-depth limit of 1 m was recorded and used for sites having a depth greater than 1 m.

Ground cover was assessed along a diagonal transect at 100 locations at evenly spaced intervals. At each point, the presence or absence of ground cover was noted, and percent ground cover for the plot was calculated by determining the percentage of sampling points within the plot with ground cover observed. At two points along the transect, where the vegetative cover was considered typical, all vegetation was clipped within a 0.5 m^2 subplot and separated into three categories; dead, live, and legumes. This provided a measure of ground cover vigor and biomass.

All trees, excluding white pine, were measured at the time of site sampling. Those over one meter tall were measured for total height, and those under one meter in height were tallied by species.

White pine measurements were conducted at the end of the growing season. Internode distances, total height and ground line diameter were measured on all white pine. One white pine per plot was cut down and the rings counted to determine the exact age.

Soil samples were returned to the lab, air-dried, sieved using a 2-mm screen to separate coarse fragments, and analyzed for particle-size distribution by the hydrometer method. Soil pH was determined in a 1:1 soil/water mixture with a glass electrode (McLean, 1982), and soluble salts were determined by measuring the electrical conductivity (EC) of a 1:5 soil/water extract (Bower, 1965). Organic matter content was determined using a LECO carbon analyzer. Kjeldahl nitrogen (N) was determined by digestion with concentrated H_2SO_4 and with an Hg catalyst. Ammonium resulting from the digestion was measured using a Technicon Autoanalyzer II. Phosphorus was extracted with $NaHCO_3$ (Olsen and Dean, 1982) and determined by spectrophotometry. Concentrations of exchangeable cations (Ca, Mg, K, Fe, Al, and Mn) were determined using a Jarrell-Ash ICAP-9000 inductively coupled plasma emission spectrometer after extraction with 1N NH_4OAC.

Multiple linear regression analysis was used to identify cause and effect relationships and to develop models for tree height as a function of minesoil properties. Selection of the best properties was made by optimizing R^2 and mean square error (MSE). Minesoil variables were transformed to optimize fit statistics.

Results and Discussion

Tree descriptions and minesoil properties are presented in Table 1. The wide range of minesoil properties depicts the variability of the measured sites. This is reflected in the variability among the heights of white pine.

The mine spoils had little or no profile development other than minimal structure and organic matter at the surface. The mine spoils varied widely in texture and generally contained 50% or more coarse fragments (>2 mm). Mine spoil pH ranged from 3.2 to 6.1.

Table 1: Means and ranges of tree growth and selected minesoil properties from 78 reclaimed mines in Virginia and West Virginia.

Tree Growth and Minesoil Properties	Mean	Range	Standard Deviation
Tree Growth			
5-yr height growth (cm)	157.0	63.6-322.7	64.7
Terminal 2-yr growth (cm/yr)	38.8	10.0-68.2	14.8
Terminal 3-yr growth (cm/yr)	32.7	10.4-56.8	12.2
Minesoil Properties			
Depth to Restrictive Layer (cm)	78.0	31.0-112.0	21.6
Rock Fraction (%)	54.1	2.0-88.0	15.4
Bulk Density ($Mg\ m^{-3}$)	1.02	0.64-1.94	0.08
pH	5.16	3.2-6.1	0.41
EC ($dS\ m^{-1}$)	0.49	0.02-11.38	1.15
Organic Matter (%)	2.19	0.11-22.9	2.84
Total Kjeldahl N (mg/kg)	567.0	156-1795	289.0
Extractable P (mg/kg)	5.49	<.06-21.8	4.8
Extractable Mn (mg/kg)	15.91	1.5-57.67	11.23
Extractable K (mg/kg)	57.5	<.3-161.6	29.0
Extractable Ca (mg/kg)	260.0	5.5-1107	228.0
Extractable Mg (mg/kg)	154.0	1.1-517	125.0
Extractable Al (mg/kg)	1.3	<.025-27.55	2.9

Generally, the greatest growth was achieved on north to northeast facing slopes exceeding 30 percent. On these sites rooting depths were greater than 60 cm, with bulk densities under 1.10 Mg m^{-3} and coarse fragment contents less than 50 percent. Nutrient concentrations were similar to those of poorer sites, with the exception of P, which was slightly higher on the best sites.

The sites with the poorest growth were located on north to northwest facing slopes shallower than 30 percent. Coarse fragment contents on these sites generally exceeded 50 percent, with bulk densities similar to those on higher quality sites and rooting depths shallower than 60 cm.

Tree densities ranged from 420 to 67,659 stems per acre with an average of 285 planted white pines per acre. White pine represented only about 5 percent of the total number of stems on the sites; the remaining stems consisted mostly of naturally seeded sourwood (Oxydendrum arboreum) and red maple (Acer rubrum), and planted black locust (Robinia pseudoacacia). Other species included Northern red oak (Quercus rubra), chestnut oak (Quercus prinus), yellow poplar (Liriodendron tulipifera), sweet birch (Betula lenta), sassafrass (Sassafras albidum), winged sumac (Rhus copallina), staghorn sumac (Rhus typhina), smooth sumac (Rhus glabra), flowering dogwood (Cornus florida), eastern redbud (Cercis canadensis), downy serviceberry (Amelanchier arborea) and black cherry (Prunus serotina).

Ground cover ranged from 30 to 100 percent, with 20 percent of the plots having less than 70 percent cover. Ground cover was predominantly orchardgrass (Dactylis glomerata), tall fescue 'Kentucky 31' (Festuca arundinacea), sericea lespedeza (Lespedeza cuneata) and red clover (Trifolium pratense).

Regression analysis was used to determine whether two and three-year terminal growth and tree height at five years of age were all related to similar minesoil properties (Table 2). Two and three year terminal growth refer to the growth per year of the final two years and three years up to age five. These measures were used to eliminate the effects of nonsoil factors that may influence seedling establishment, such as seedling quality, planting shock and ground competition. Brown and Stires (1981) determined that early growth is often affected by nonsoil properties, but once past the establishment phase, growth is more related to edaphic factors. These values cover different years, depending upon the age of the tree. Therefore, weather variations among years could contribute to variability in growth among trees. To eliminate this effect, a "free-to-grow" point was determined. This was defined as the average annual growth rate that occurred after the year that height growth exceeded the average of the two previous years by 100%.

In this study, three factors- slope percentage, phosphorus, and depth to a restrictive layer - were correlated most strongly with two year terminal growth. Three year terminal growth and five year height growth were also correlated with these factors, but less significantly (Table 2). The "free-to-grow" point showed no correlations at the 0.05 level of significance.

Table 2: Correlations of minesoil properties and tree growth on 78 reclaimed mines in Virginia and West Virginia.

Minesoil Property	5-yr. Height P > F	5-yr. Height r	Terminal 2-yr P > F	Terminal 2-yr r	Terminal 3-yr P > F	Terminal 3-yr r
Depth	0.009	0.36	0.000	0.49	0.000	0.48
Rock Fraction	NS*		NS		NS	
Sand Fraction	NS		NS		NS	
Clay Fraction	NS		NS		NS	
Bulk Density	NS		NS		NS	
pH	NS		NS		NS	
EC	0.003	-0.33	0.020	-0.28	0.037	-0.24
Organic Matter	NS		NS		NS	
Total Kjeldahl N	NS		NS		NS	
Extractable P	NS		0.000	0.40	0.001	0.37
Extractable K	NS		NS		NS	
Extractable Mn	0.002	-0.35	0.030	-0.25	NS	
Extractable Ca	NS		NS		NS	
Extractable Mg	NS		NS		NS	
Extractable Fe	NS		NS		NS	
Extractable Al	NS		NS		NS	
Slope	0.022	0.26	0.000	0.46	0.000	0.43
Aspect	NS		NS		NS	
Bare Soil	NS		NS		NS	

*NS = not statistically significant at the .05 level

In this study, rooting depth was the property most highly correlated with height growth. The height of white pine was plotted as a function of the natural log of rooting depth (Figure 2a). Although there was considerable variability among sites, indicated by the scatter of data about the regression line, there was an obvious upward trend to a depth of 60 cm. In deeper soils the relationship was not apparent (Figure 2b). Soils deeper than 60 cm had little or no effect on height growth at age five.

Throughout the range of white pine, soil depth is an important limiting factor. Meltzer (1964) noted that among six associates, white pine had the poorest ability to penetrate a compacted mineral subsoil (Larix decidua > Pinus silvestris > Betula verrucosa > Alnus incana > Picea abies > Pinus strobus). The depth of minesoils can be limited by underlying bedrock, compaction from heavy equipment, or large boulders (Torbert et al., 1988). Deeper soils provide a greater exploitable rooting volume, nutrient supply, and moisture-holding capacity.

The correlation between height growth and slope percent indicated that tree growth was adversely affected by shallow slopes (Figure 3). This finding conflicts with the generalization that steeper slopes provide poorer growth on undisturbed forest sites. Shoulders and Tiarks (1980) concluded that, generally, as slope steepness increases, stand basal area decreases due to excessive runoff and shallow soils. However, on minesoils, flatter bench sites are often subjected to greater vehicle traffic, resulting in higher soil bulk densities and, thereby, decreasing growth. On steeper slopes, reclamation equipment use is restricted, resulting in less compaction. This finding is reflected in the data; as the slope increases bulk density decreases.

In this study two different expressions of the interaction of slope and aspect were investigated; it is assumed

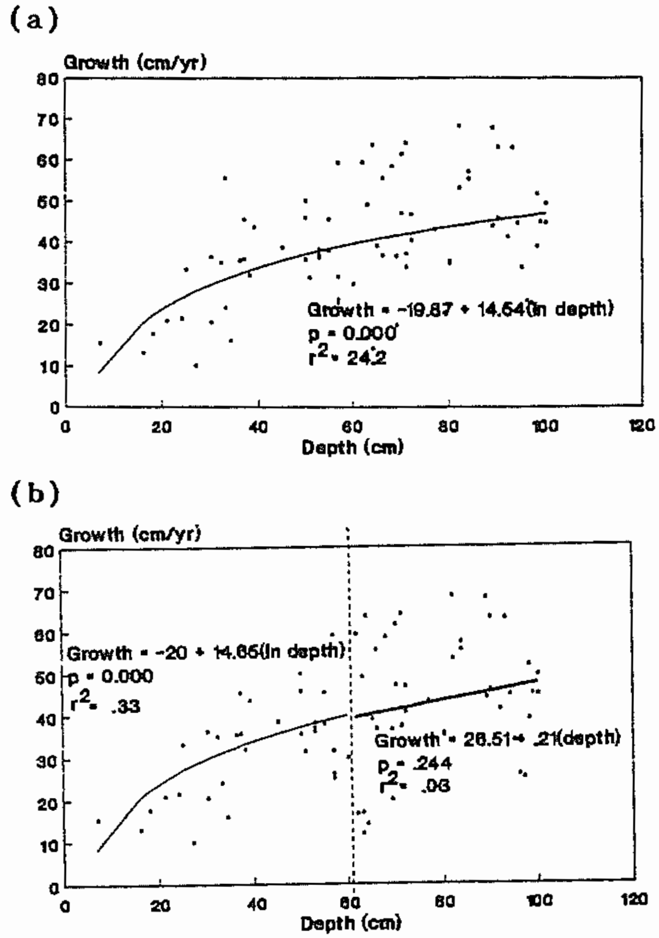

Figure 2. Relationship between white pine 2-year terminal growth and soil depth; (a) regression analysis performed on complete data set; (b) regression analysis performed on soils less than 60 cm and greater than 60 cm.

that, on steeper slopes, aspect has a greater effect on growth. The first expression, proposed by Beers and others (1966), is mathematically stated as B cosine (a-O) where B is the amplitude, a is the azimuth and O is the phase shift that has historically been assumed to be 45°. An expression of aspect and slope was also developed by Stage (1976) in which the combined effect of slope and aspect were defined as the tangent of slope percent times the sine and cosine, respectively, of the azimuth. Neither expression significantly improved upon the slope variable alone.

This study indicated that an increase in phosphorus content increased height growth (Figure 4). Phosphorus is a constituent of important organic compounds involved in metabolism and energy transfer in plants. Phosphorus deficiencies are widely recognized as a major plant limiting growth factor in the Appalachian region (Barnhisel and Massey, 1969; Smith and Sobek, 1978; Howard 1979; Daniels and Amos, 1984). Reasons for phosphorus deficiencies in minesoils usually include one or more of the following: i) over-burden materials contain only small amounts of phosphorus-bearing minerals; ii) phosphorus compounds that are present are insoluble, especially in very acid or alkaline materials, and iii) there is no reservoir of organic phosphorus compounds (Vogel, 1981). Even when P fertilizers are applied they are often fixed into unavailable forms.

There was a significant correlation between growth and the square root of P content. For many plants the soil P critical level is 10 ppm using the $NaHCO_3$ extraction method (Ministry of Agriculture Fisheries and Food, 1973). In this study, many trees grew well in the P deficient zone (Figure 4). This good growth may have been due to mycorrhizal colonization of tree roots, allowing exploitation by hyphae which may reach several centimeters from the root surface. This may result in the uptake of several times more phosphorus per unit root length than with nonmycorrhizal roots. Mycorrhizal fungi excrete organic acids that dissolve phosphorus compounds in the rhizosphere. According to Bolan et al. (1984), mycorrhizal roots are able to utilize phosphorus sources

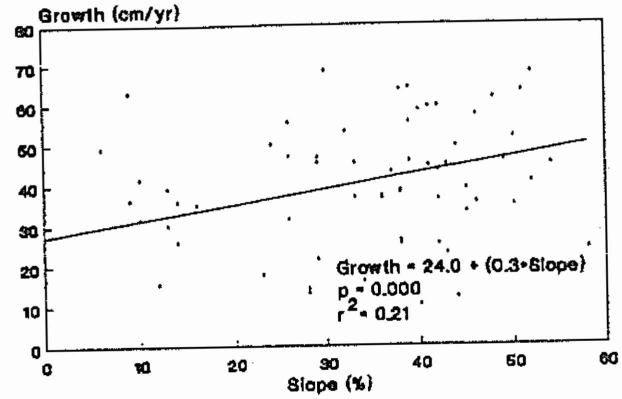

Figure 3. Relationship between white pine 2-yr terminal growth and slope.

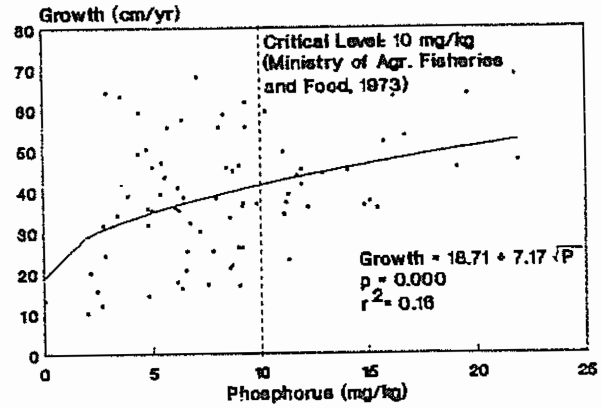

Figure 4. Relationship between white pine 2-yr. terminal growth and soil P.

that are normally unavailable to nonmycorrhizal roots.

Another variable that was correlated less significantly with growth was electrical conductivity. The negative correlation indicated that growth was adversely affected by high levels of soluble salts. Salinity may affect different metabolic processes, such as CO_2 assimilation, protein synthesis, respiration and phytohormone turnover (Mengel et al., 1982). Due to rapid weathering of newly exposed minerals, minesoils often have high levels of soluble salts (Torbert, 1988). These high levels usually decrease with time due to leaching.

Multiple regression analyses indicated that inclusion of variables other than those found significant in single factor correlations did not greatly improve the model for terminal three year height growth or for five year height growth. No model was significant for the free-to-grow point. The best model for terminal 2-year increment (Eq. 1) included four variables; rooting depth (natural log), phosphorus (square root), slope and soil manganese.

Terminal 2-yr increment = $-11.13 + 9.3\ln(\text{depth}) + 4.37\text{sqr}(P) - 0.332(Mn) + 0.189(\text{Slope})$ [1]

$R^2 = 0.42$

Soil manganese, alone, had a low significance value, but its inclusion improved the overall model for predicting 2-year terminal height growth. Although this may result in "overfitting" the model, there may be some biological reasons for its inclusion. In this study, there was a decline in growth when extractable soil manganese levels exceeded 30 ppm, indicating a possible toxicity. Manganese toxicity commonly occurs in strongly acid soils or in waterlogged soils. Barnhisel and Massey (1969) found that contents of available manganese in eastern Kentucky spoils approached toxic levels, hindering the establishment of vegetation.

Conclusions

Results of this study indicated that favorable height growth can be achieved on certain reclaimed mine sites in Virginia and West Virginia. Tree growth was found to be, primarily, a function of depth to a restrictive layer, slope, and phosphorus content. The addition of soil manganese resulted in an improvement of the model, but still left more than half of the variation in tree growth unexplained. Most of the factors affecting tree growth in this study can be manipulated by mine operators to promote greater white pine growth and to increase stand value on reclaimed mine sites.

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