INFLUENCE OF PHYSICAL, CHEMICAL, AND BIOLOGICAL MINE SOIL PROPERTIES ON WHITE OAK SEEDLING GROWTH[1]

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Abstract. Landowners in the Appalachian region are becoming increasingly interested in restoring the native hardwood forest on mined land after reclamation. Trees are usually planted in topsoil substitutes consisting of blasted rock strata from the geologic profile. Reforestation attempts using native hardwoods have often been unsuccessful due to the highly variable nature of the physical, chemical, and biological properties of mine spoils. The purpose of this study was to determine which mine soil properties most influence white oak seedling growth, and to test whether or not these properties are adequately reflected in a preliminary mine soil classification model. Seventy-two 3-yr-old white oak trees were randomly selected across a reclaimed site in southwestern Virginia that varied greatly in spoil type and site properties. Tree height was measured and soil samples were taken to a 40 cm depth at the base of each tree and analyzed for physical, chemical, and biological properties hypothesized to influence tree growth. Tree height and biomass, which ranged from 15 to 125 cm, and 0.24 to 190.03 g, respectively, were regressed against mine soil and site properties. Potassium, size of microbial populations, extractable nitrogen, pH, soil texture, aspect, and phosphorous accounted for over 52% of the variability in tree growth. This study indicates that white oaks are most successful growing on east-facing aspects, in slightly-acidic, sandy loam textured, fertile mine soils that are conducive to soil microbial activity. These results suggest that sandstone rock types with suitable chemical properties should be selected for topsoil substitutes when native hardwood restoration is the desired post-mining land use.

Additional Key words: Site index, microbial biomass, native hardwoods

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[1] Paper was presented at the 2005 National Meeting of the American Society of Mining and Reclamation, June 19-23, 2005. Published by ASMR, 3134 Montavesta Rd., Lexington, KY 40502.

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Proceedings America Society of Mining and Reclamation, 2005 pp 1029-1041
DOI: 10.21000/JASMR05011029
`https://doi.org/10.21000/JASMR05011029`

Introduction

The eastern deciduous hardwood forest of Appalachia is one of the most valuable, productive, and diverse temperate forests in the world. It is important, both environmentally and economically to the seven states in the Appalachian region. However, large areas of this forest are being eliminated due to surface mining, and few of these native stands are restored after mining is completed.

Over 500,000 ha of land have been surface mined in the eastern United states since the implementation of SMCRA in 1978 (OSM, 1999). Federal and state regulations based on SMCRA have helped improve water and environmental quality as well as safety of active and reclaimed sites, but current reclamation procedures are not conducive to reforestation (Burger and Zipper 2002). These large areas of land have mostly been reclaimed to grassland or wildlife habitat (grassland with wildlife shrubs). Reclamation usually involves the replacement of the landscape to approximate original contour and planting with an herbaceous ground cover. Many reclaimed grassland sites have low productivity and are often abandoned due to their poor quality and remote location. Return of the native forest would create a valuable economic resource as well as play an important role environmentally as forest ecosystem services such as watershed control, water quality, carbon sequestration, and wildlife habitat are restored.

Due to the steep slopes of the Appalachian Mountains, returning land to approximate original contour is often unfeasible or expensive. In West Virginia, commercial forestry is an acceptable land use on mines for which a waiver of the approximate original contour requirement has been obtained. Reforestation is an attractive alternative under these circumstances, but, in order for coal operators to get bond release, tree growth must be successful, with a site index comparable to adjacent native forest.

Black locust and a variety of other early-successional trees are able to survive and grow on these mined sites (Vogel and Berg 1973; Filcheva et al. 2000). However, these species have little commercial value for land owners and do not provide the same level of ecosystem services as the native late-successional hardwoods that are usually present prior to mining.

The survival and growth of late-successional, commercially valuable, native hardwoods on reclaimed mine sites is often poor. This is due to a combination of factors including herbaceous competition, management practices, and spoil properties. Mine spoils have highly variable physical and chemical properties, ranging from very acid pyritic materials to alkaline shales. Compared to native soils, mine spoils can be high in rock fragments, have low moisture content, low porosity, poor structure or high bulk density (Bussler et al., 1984). Chemical properties such as high pH and soluble salts or low nutrient levels can also adversely affect tree growth (Torbert et al., 1998).

In this area where fire and other disturbances are common, oaks represent a mature successional stage in forest development (Johnson et al, 2001). They are an essential component of the native hardwood forest and their replacement on these sites is an invaluable step toward the return of these forests. Due to their large tap root, they are drought tolerant suggesting that once established they could compete on these harsh sites. However, the chemical and physical properties of the soil medium play an important role to their development. This study addresses the question of how these different spoil properties may affect oak growth.

Understanding how the combinations of different properties affect tree growth would aid in classifying and mapping mined land, and in developing successful forest practices. When blasted rock is placed on the surface, materials that would be more conducive to growth can be chosen. Sites can be mapped and tree species selected based on site and soil types. Some species are better at growing on more acid sites while others can tolerate high pH. Fig. 1 depicts species selection for commercial hardwood growth in the Appalachians depending on site quality. This model is based on compaction, pH, and spoil texture.

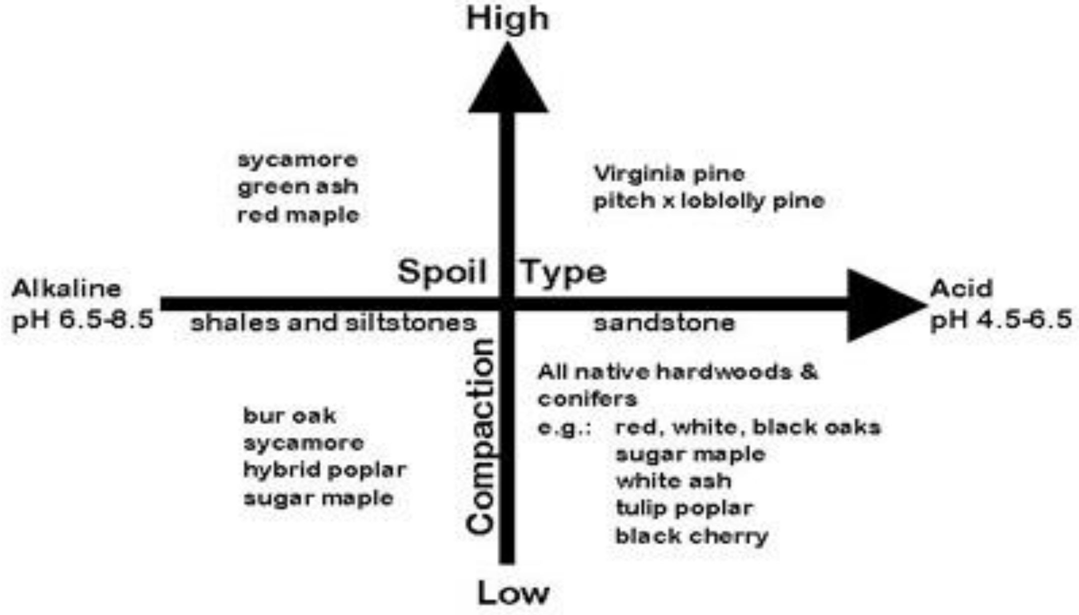


Figure 1. Tree species recommended for different soil types and levels of compaction in the Appalachians (Burger 2002).

Assessing site quality and forest health after trees have been planted is also important. It can help to determine why tree planting may not have been successful and what amendments should be made to improve chances of success in the future. The objectives of this study are to: 1) test the accuracy of a site quality classification model (Burger et al. 2000) using a reforested mined site containing a broad gradient of spoil types and potential site quality classes; and 2) to understand the relationship between mine soil properties and white oak growth in order to improve the usefulness of the model.

Methods and Procedures

A previous study involving 10 reclaimed sites across 3 states was used to develop mine soil quality classification criteria based on aspect, rock type and bulk density (Burger et al., 2002). These three criteria were measured and regressed against tree growth on all plots. The slopes of the regression lines for each of these variables were used to develop weighting factors for each criterion in order to create an overall soil/site quality class (Fig. 2). Sites can be given a rating for each of these variables, multiplied by their respective importance factors, and added together to find the final soil/site quality class. The resulting class can then be used to decide on a planting regime for each of the mapped sites.

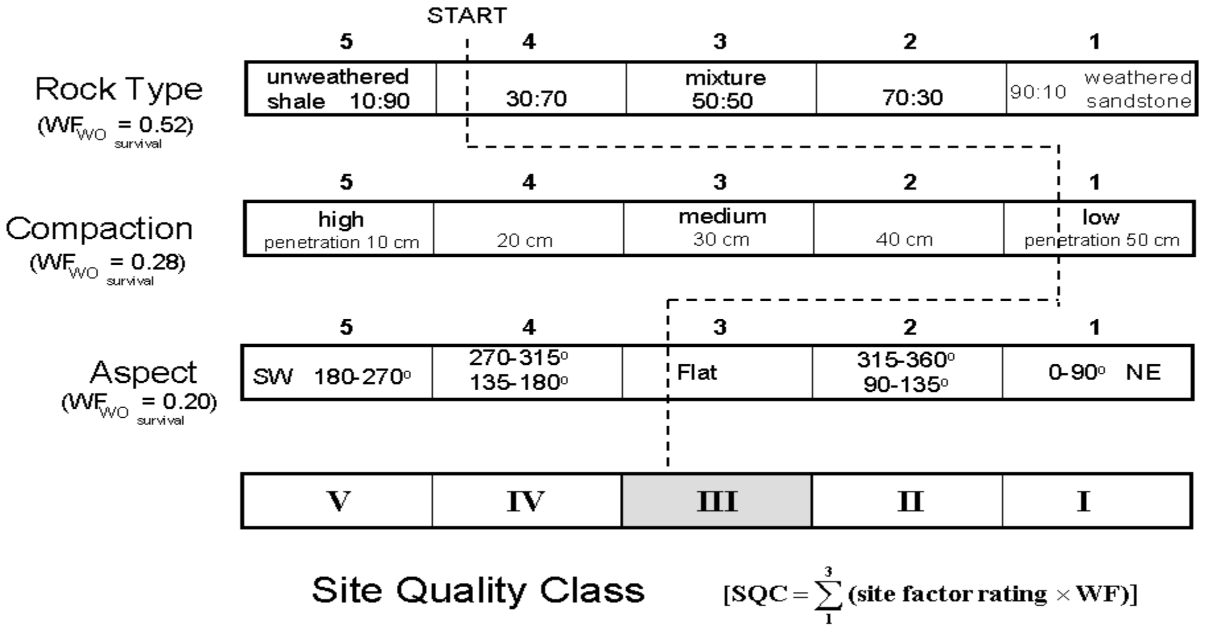


Figure 2. Site factor gradients used to determine overall mined site quality class (SQC) (Burger et al., 2002).

This study was conducted during the summer of 2004. The study area is located in southwestern Virginia on a reclaimed coal mine owned by Rapoca Energy Co. (Fig. 2). This area is in the Kanawha geologic formation and many different rock strata above the coal seam were placed on the surface during reclamation. As a result, the area consists of a wide variety of mine soil types, varying in both physical and chemical properties.

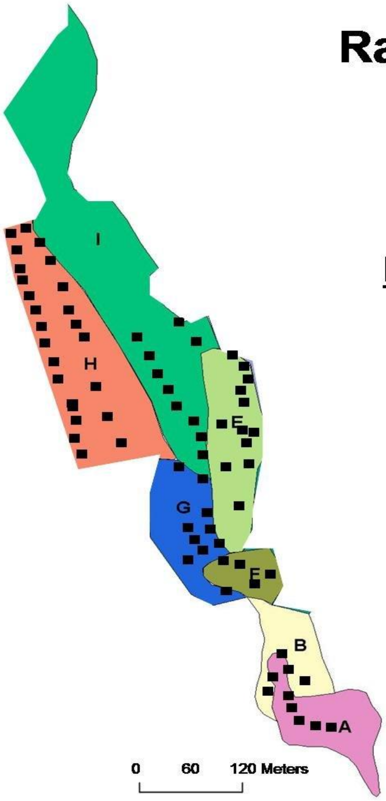
In 2001, immediately after final grading, reclaimed soils were mapped and areas of the site with similar mine-soil properties were delineated as soil mapping units. For each mapping unit, site quality class, using the criteria of Burger et al. (2002), was assigned (Fig. 4). The site was planted in 2002 with native hardwoods at a density of 1482 trees per ha using species mixes appropriate to each mapping unit’s soil properties and site quality.

Tree performance was used to judge the accuracy of the site class assignments. Seventy-two three-year-old white oak trees were randomly chosen across a range of spoil types, including 5 mapping units (Fig. 4). White oak was chosen because it was a component of all species mixes and is a valuable timber species of the late successional native forest of the Appalachians. Glyphosphate was sprayed in a 1m circumference around each tree to reduce herbaceous competition at the beginning and in the middle of the growing season. Tree heights were measured at the end of the growing season, and averages were calculated for each mapping unit.

Figure 3. The Rapoca reclamation site in southwest Virginia immediately after reclamation, 2002.

Soils were analyzed in the lab in order to determine other parameters influencing tree growth that might be used in mapping and site classification. Soil samples were taken to a 40 cm depth within a 50 cm radius from the base of each tree. Samples were dried and sieved through a 2 mm sieve and an array of physical and chemical properties were measured (Table 1). The site factors aspect, slope, and distance from native forest were also determined for each tree.

At the end of the growing season, the trees were excavated and soil within a 2cm diameter of the roots was used for the characterization of soil microbial properties (Table 1). This area is slightly larger than the rhizoshpere so as to yield enough soil in this zone to carry out the needed analyses. Soil was kept at 4ºC and was processed within 2.5 weeks of collection. The ATP procedure was modified for the analysis of soils. Soil was placed in a saline solution and shaken for an hour to get microbial populations into solution. The samples were then centrifuged at 1000 rpm to remove particulate matter while allowing microbes to remain in solution. This solution was then used in the standard ATP procedure (ATPlite, 2002).



Rapoca field units. Based on GPS points and 1999 aerial photo.

Unit Label	Rock Type	Compaction	Aspect	Site Quality	Site Class
A	2	2	3	2.2	II
B	4	3	3	3.5	IV
E	2	4	3	2.8	III
F	3	2	4	2.9	III
G	4	4	5	4.2	IV
H	5	3	4	4.2	IV
I	1	1	5	1.8	II

Figure 4. Soil/site quality classification and mapping for the Rapoca reclamation site in southwestern Virginia. The points indicate randomly selected white oaks that were used for mapping evaluation and regression analysis of mine soil properties.

Data were analyzed using multiple regression analysis (SAS, 2004). The independent variables were transformed based on interactions with tree growth. Potassium and available nitrogen were transformed using the square root function. Microbial biomass and pH were transformed using a natural log function and an arc sine function was used to transform aspect in order to make it a continuous variable. Backward, Cp and R-squared selection were used to eliminate variables based on multi-collinearity and biological significance. Two experimental units were eliminated based on differences in growth pattern. One had a double stem while the other was much larger than any of the other trees. Two additional outliers were eliminated based on soil properties. Both had phosphorous levels over ten times higher than any of the other samples. This was most likely due to an error during lab analysis.

Table 1. Soil physical chemical and biological properties tested on the Rapoca reclamation site in southwestern Virginia, 2004. Italicized bold properties were included in the final regression model.

Soil/Site Property	Analysis	Authority or Reference
Aspect		
% Slope		
Distance from native forest		
Bulk density		
Texture	Particle Size Analysis	(Bouyoucos, 1936) (3 other references)
Coarse fragment content		
Total soluable salts	Electrical conductivity	(Bower and Wilcox, 1965)
N availability	Anaerobic incubation	(Bremmer, 1965b)
Inorganic N (NH4 and NO3)	KCl extraction	(Bremner, 1965a)
pH		
Total N and C	Carbon nitrogen analyzer	(Vario MAX)
Exchangable cations (Na, Ca, Mg, K)	Ammonium acetate method	(Thomas, 1982)
Available nutrients (P, ***K***, Mg, Zn, Mn, Cu, Fe, B)	Mehlich I	
Available P	Sodium bicarbonate method	(Olsen and Sommers, 1982)
Microbial activity	ATP assay	(ATPlite, 2002)
Microbial enzyme concentration	Dehydrogenase assay	(Tabatabai, 1982)
Microbial biomass	Chloroform fumigation	(Anderson and Domsch, 1978;Gregorich et al., 1990; Jenkinson and Powlson, 1976)

Results and Discussion

Average tree growth for each mapping unit was plotted as a function of site quality class (Fig. 5). The data show a weak trend of decreasing tree height on poorer site quality classes, where Class 1 is highest quality and Class 5 is lowest quality. However, the relationship between tree growth and the designated site class for the mapping units was not significant (P>0.05), suggesting that soil and site factors in addition to those used in the classification model (Burger et al., 2002; Fig. 2) may be influencing growth. Site class was incorrectly assigned to several of the mapping units based on tree height. The results of this analysis indicate that that the classification and mapping criteria need to be improved in order to be useful.

In order to better understand which soil and site factors were influencing white oak seedling growth, and in order to determine additional classification criteria to improve the model (Fig. 2), tree height was regressed against soil and site properties using individual tree data (Table 1). From greatest to least importance in the regression model, potassium concentration, microbial biomass, total extractable nitrogen, pH, % silt plus clay, aspect, and phosphorous concentration were found to be the most important factors for white oak growth on this site (properties shown in bold in Table 1).

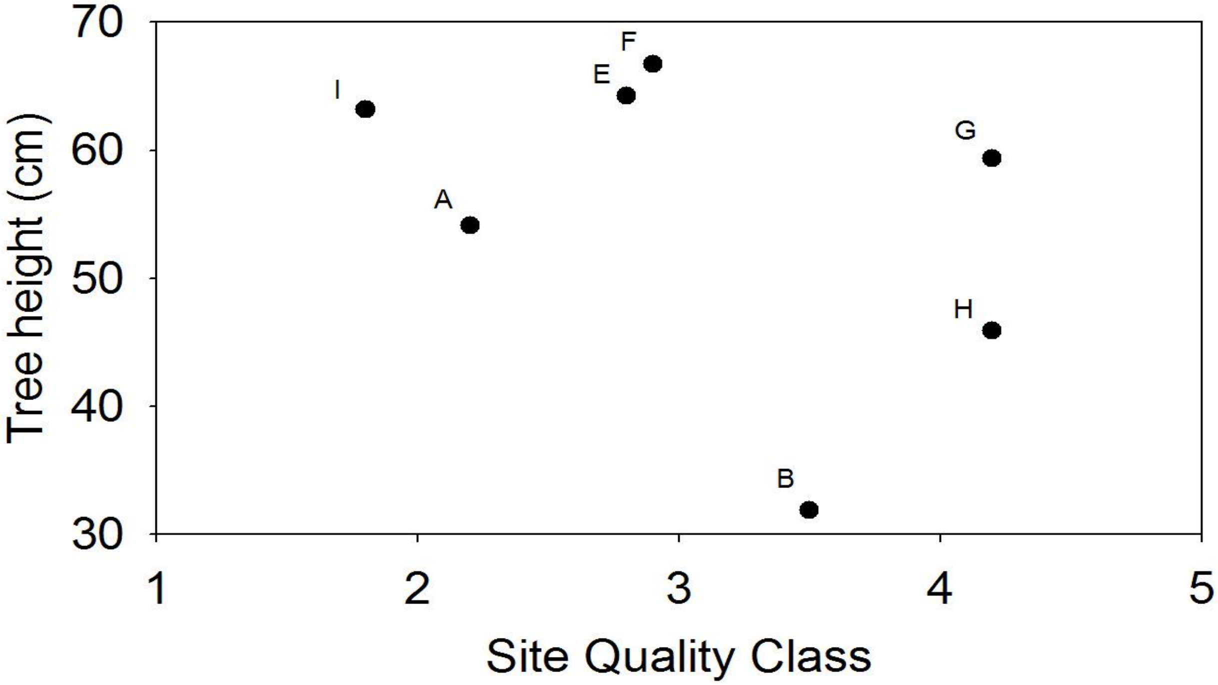


Figure 5. Mean tree height verses soil/site quality for mapping units on the Rapoca reclamation site in southwestern Virginia, 2004.

The nutrients phosphorous, potassium and nitrogen were positively correlated to tree growth and were found to be statistically significant components of the regression model. The trees were most likely responding to fertilizer applied when the site was hydro-seeded with herbaceous ground cover when planting occurred in 2002. Although these applied nutrients are not an intrinsic property of the mine spoils, their variation in abundance is an indicator of how well the different spoils retain them. Tree growth was a function of the square root of the level of N and K and the linear level of P. These are well-established relationships between nutrients and tree growth. Potassium is also an indicator of other nutrients in the soil. During the regression analysis, other nutrients that were collinear with potassium such as calcium and magnesium were eliminated. This nutrient can thus be seen as representing a group of cations important to tree growth. The average level of nitrogen measured across the study area was 4 mg/kg (Fig. 6). This level is considered deficient (Fisher and Binkley, 2000), suggesting that the higher levels found on some sites would have a positive impact on tree growth.

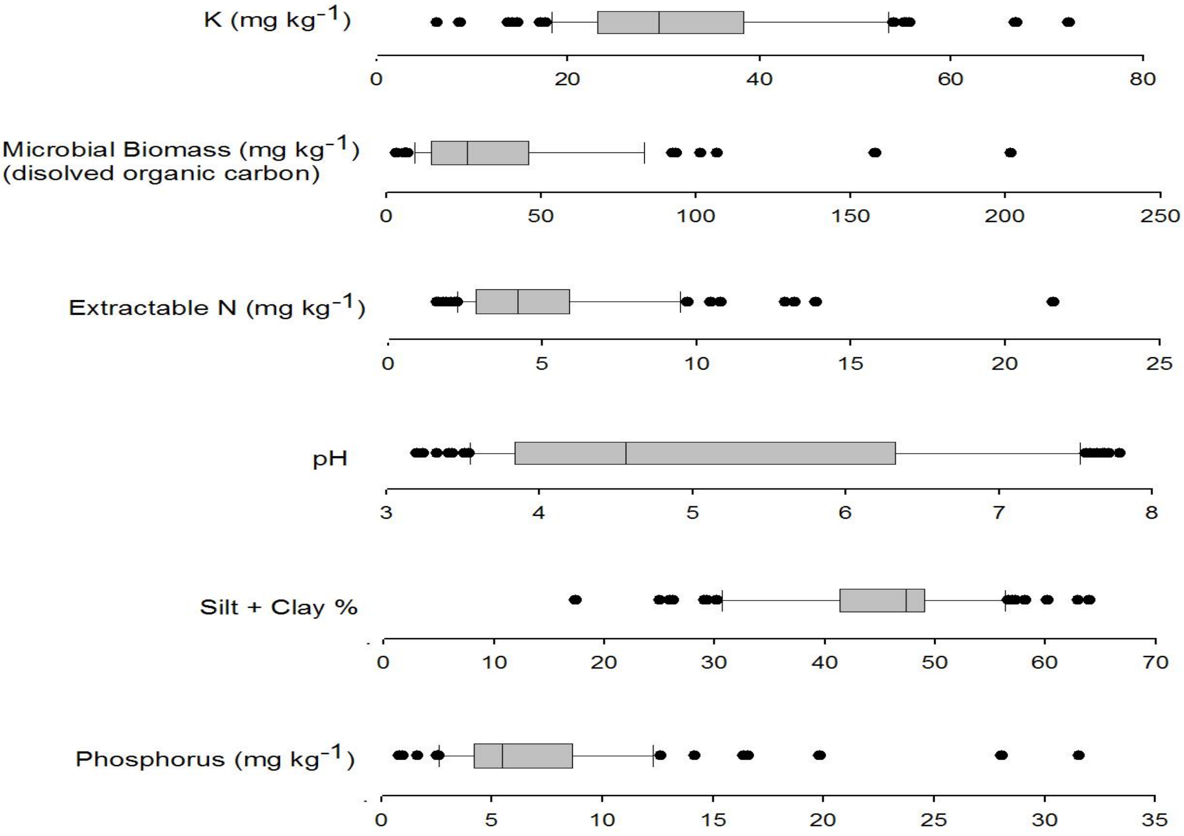


Figure 6. Boxplots for variables in the regression model, listed from most to least important to tree growth.

Microbial biomass was positively correlated to tree growth. Since correlation does not necessarily imply causation, it is unknown whether microbial populations have a significant effect on tree growth or whether microbial growth responds to other site factors that influence tree growth. The fact that microbial biomass was independent of other regressors in the model suggests microbial growth as a causative factor. In any case, microbes are a good indicator of soil health (Miller, 1998). Hutson (1980) found that low population densities of organisms on industrial reclamation sites led to significantly less degradation of oak leaves than on control sites. This lack of soil organisms in mine spoils may result in poor soil development and thus lower tree survival and growth. In his discussion of techniques for reclaiming with native hardwoods, Miller (1998) stated that the development of a healthy and diverse soil microorganism population through replacement of topsoil is essential to the establishment of native trees. These microbes are the main mechanism for the release of plant available nutrients from organic matter (Brady and Well, 1996).

Percent silt-plus-clay was negatively correlated to tree growth. Soil types ranged from loamy sands to sandy clay loams with 17 to 65% silt-plus-clay (Fig. 4). This negative correlation suggests that oak trees prefer to grow in sandier mine soils. This may be caused by low hydraulic conductivity and poor drainage in the more finely-textured mine soils, or it may be because silt-plus-clay corresponds with chemical factors that influence tree growth. Torbert (1998) also found a strong positive correlation between percent sand and tree growth.

Nearly 56% of the variability in tree height was described by the 7 soil and site factors:

$$Tree\ ht = 43.73 + 6.75\sqrt{(K)} + 8.81\ln(bio) + 10.87\sqrt{(N)} - 24.95\ln pH - 0.71(siltclay) - 13.97\arcsin(as) + 0.39(P)$$

$R^2 = 0.5281$

Table 2. Variables and standardized coefficients for the above regression model describing 52% of the variation in tree growth.

Variable	Standardized coefficient
K = potassium (mg kg^{-1})	(0.38955)
Bio = biomass of microbes (mg L^{-1})	(0.38014)
N = total extracted nitrogen (mg kg^{-1})	(0.36489)
pH = pH	(-0.34344)
Siltclay= % silt + clay	(-0.31567)
as = aspect	(-0.30660)
P = phosphorus (mg kg^{-1})	(0.10646)

This regression model supports and can add to the original classification model (Fig. 2) in several ways. Silt plus clay is clearly reflected in the rock type criterion. There is a direct parallel with aspect in both the original classification model and the regression model, with north east aspects being the most conducive to tree growth because they are cooler, wetter areas. An expression of compaction or soil density did not appear in the regression model. Soil density is difficult to measure experimentally, and its influence can be confounded by coarse fragments and other factors. However, compaction has been extensively documented as playing an important role in tree growth on reclaimed sites and should be included as a criterion for site mapping and classification.

Nutrients and microbial biomass are also important criteria of soil quality. However, these variables are not easily measured in the field and thus may not be useful additions to the field mapping criteria. Some nutrients, however, are a function of pH, a variable that can be measured easily in the field.

Soil reaction has been used in the past to assess mine soil quality for agronomic crops, but it is often modeled as a positive linear relationship with productivity for all situations, where a higher pH indicates a better soil. Although pH levels up to 6.5 can lead to an increase in phosphorus availability and CEC, circumneutral pH's can decrease the availability of some micronutrients and shift microbial composition, especially mycorrhizal relationships on which native trees depend. High pH can also lead to other complications to tree growth such as herbaceous competition. At high pH's grasses have a distinct advantage and often out-compete trees (Burger and Zipper, 2002). This suggests that pH should be judged as tree and site specific and could be added as an additional criterion for soil classification and mapping.

Conclusions

Tree growth was somewhat correlated with the previously developed mine soil classification criteria (Burger et al., 2002) but additional criteria were needed for adequate mapping. The regression model shows that sandy loam soils with a north east aspect, high nutrient levels, and high microbial populations are the most conducive to growth of white oak on the Rapoca reclaimed mine site. Of these properties, texture and aspect are criteria in the existing classification model (Burger et al., 2002). The other properties are largely dictated by the pH of the soil, which is an easily measured property that could be included as a classification criterion.

The combination of pH with aspect, rock type, and bulk density could serve as a solid foundation for forest site quality classification and mapping. If known interactions between these factors and late successional tree growth are kept in mind, these more valuable trees can be selected and planted accordingly, leading to increased survival and growth by planted seedlings, a better chance of timely bond release for miners, and a better chance of restoring a healthy native hardwood stands.

The next step would be to remap these areas with the added criterion of pH. These new mapping units could then be correlated with tree growth. If adding pH improved the accuracy of soil/site quality designations, mapping of potential forest productivity could facilitate improved native hardwood planting and management on reclaimed strip mined sites. This improved success would lead to a faster and more productive return of the forest that was there prior to mining.

Acknowledgements

We would like to thank the Powell River Project, Department of Energy project: DE-FC26-02NT41619 , and the Rapoca Energy Company for making this research possible.

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