TREE RESPONSE TO SUBSTRATE AND GRADING TREATMENTS ON QUARRY OVERBURDEN[1]

V. De Lima[2], J.A. Franklin, and D.S. Buckley

Abstract: Rock quarries are often in close proximity to residential areas. Consequently the re-establishment of forest vegetation is desirable. However, reclamation methods for the eastern US have been developed primarily for the coal mining industry, on overburden which differs in chemical and physical properties from quarry overburden. The objective of this study was to test the material placement technique used for reforestation in coal mine reclamation, and to determine whether lime or nitrogen application will enhance early tree growth on this overburden material. Twelve rectangular plots were constructed of overburden materials from a limestone quarry. Six of the plots were lightly graded with a single pass of a bulldozer, and the other six remained ungraded. Liquid lime was applied to one half of each plot, and fertilizer (20:20:20) was applied at a rate that provided 100 Kg/ha or 400 Kg/ha N to randomly selected plots in a manner that created three replicates of all lime, fertilizer, and overburden placement treatment combinations. Monocultural blocks of *Castanea dentata* (American chestnut), *Pinus echinata* (shortleaf pine) and *Quercus alba* (white oak) nursery seedlings were planted on 1 x 1 m spacing in all treatment combinations. All three species showed a positive growth response to the higher fertilizer application rate. This response to fertilizer was pronounced in both chestnut and white oak, but these species showed no growth response to lime application. Shortleaf pine showed reduced growth in root collar diameter and height in response to lime, although the reduction in diameter growth was overcome by the addition of more fertilizer. The growth of both chestnut and pine was negatively affected by single-pass grading and interactions between grading and soil amendment treatments were found. At this stage of the study, it can be concluded that interactions between pH, nutrients, and material placement can have an important influence on the post-planting performance of different tree species.

Additional key words: soil amendments, reforestation, nitrogen, pH

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Introduction

As found in other industries that result in severe soil disturbance, reclamation activies on quarry material have consisted primarily of slope stabilization through the planting of aggressive grasses and other herbaceous cover crops. Quarrying often occurs in close proximity to human population centers and is highly visible, but also has great potential for providing ecosystem services when quarries are reclaimed. The planting of trees on quarry overburden can act as a visual and sound buffer between residential areas and ongoing mining activity, and provide potential long-term services of commercial forestry, recreation, and wildlife habitat. However these materials differ both physically and chemically from coal mining overburden, on which tree establishment has been studied in some depth in this region.

Multiple studies have investigated the suitability of different tree species for reforestation of reclaimed coal mines, and results from various regions suggest many native tree species, including commercially important species such as pines and oaks, are viable choices (Torbert and Burger, 2000). Investigations aimed at identifying appropriate matches between tree species and different regions, overburden materials, landform positions, and microsites are underway, but in the eastern U.S., the greatest body of research is on coal mine materials. Quarry overburden materials are similar to coal mining overburden materials in terms of being essentially devoid of organic matter, and seeds and other propagules of plants, but may differ chemically due to underlying geology. One definitive result of coal mine reforestation research that is likely to be universally applicable is that excessive compaction of overburden materials after placement is highly detrimental to the growth and long-term survival of planted trees. Some amount of compaction is inevitable, and substantial compaction of deeper horizons is often necessary to stabilize new landforms constructed with overburden materials. The current recommendation is to minimize compaction of at least the top 4 feet of overburden material in order to improve percolation of rainfall, reduce runoff, improve aeration, and ensure adequate rooting space for planted trees (Sweigard et al., 2007).

Other characteristics of landforms created by the placement of overburden materials, such as micro- and macrotopography, have the potential to influence establishment of tree species, but investigations of the effects of deliberately created topographical features have been limited. Macrotopography generally refers to visible features such as hills and ridges, which influence drainage and water movement, and can alter the environment by changing the duration of intercepted sunlight, which affects soil temperature, evaporation, and nutrient cycling. Microtopography generally refers to features less than 0.3 m in height, or the roughness of the surface. These features influence water infiltration rates, evaporative surface area, and the likelihood of collecting wind-blown seeds. The material placement method influences macro-topography, while grading generally reduces micro-topography as well as increasing the density of soil.

A number of site preparation practices for mine reclamation have been adapted from agriculture, including nitrogen fertilization and liming. Application rates are often based on optimum soil chemistry for agronomic herbaceous species (typically pH 6-7) to promote the rapid establishment of ground cover, and because few guidlines exist for the establishment of native forest. Fertilizer application represents a considerable investment, however, and there is little evidence of any long-term benefit of initial fertilization on species diversity or biomass production (Jochimsen, 1996). Fertilizer addition may also exacerbate the problem of competition between planted trees and aggressive, agricultural groundcovers (Simpson, 1978). Conditions created by fertilization and liming differ significantly from conditions in natural forests, to which native species are best adapted. Soils in the pH range of 4 – 5.5, typical of much of the untreated quarry overburden in this area, are capable of supporting native forests. Low pH does interact with high soil compaction to limit plant growth, and while lime addition alleviates nutrient deficiencies associated with pH below 4 and facilitates establishment of non-native, agricultural grasses, it may also induce deficiencies in Mn and Zn in minesoils of this region (Ott, 1978).

The successful establishment of a planted tree seedling is largely a function of its ability to overcome transplant shock. Transplanting disrupts water and nutrient uptake, and the ability to acclimate to new conditions is dependant upon the pre-planting conditions and physiological status of the individual (Close et al., 2004). Post-transplanting success is primarily a function of the ability of the roots to regenerate and re-establish tree water relations and nutrient uptake (Grossnickle, 2005; Sands, 1984). Because direct measurement of root growth rate on minesites is difficult, an indirect estimation of root function can be made through measurements of leaf function. Transpiration rate is mediated by stomatal opening, which responds to conditions at the root (Aston and Lawlor, 1978), and thus can be used as a rapid estimator of root recovery in planted seedlings.

The objective of this study was to test the establishment of native trees on quarry overburden with respect to: 1) macrotopography created by different overburden placement techniques, 2) nitrogen fertilization and 3) lime application. Here we present the first year performance of trees planted into a full factorial experiment designed to test the effects of lime application, two levels of nitrogen fertilization, and loosly placed overburden vs. single-pass grading.

Materials and Methods

Material placement

The experiment is located on a 5 hectare experimental valley fill on the University of Tennessee Forestry Research and Education Center, in Oak Ridge, TN. Overburden materials from current limestone quarry operations at Rogers Group, adjacent to the site, were placed in a manner consistent with the Forest Reclamation Approach (FRA) (Burger et al. 2005). This was a poorly consolidated, sedimentary, weathered material that overlaid the quarried limestone, and rapidly broke down to a soil-like material with a high percentage of durable rock fragments (3-40 cm in size). The pH ranged from 5.1 to 5.5, exchangeable P from 0.11-0.35 ppm, EC from 73-242, and N was below detection limits. Over a compacted base, fresh material was placed in loosely-dumped piles, with piles arranged in a row. When initially placed, piles were approximately 2 m in height, to ensure that the recommended 1.2 m depth of uncompacted material would be present after substrate settling. Rows of these piles were arranged on site such that drainage flows downhill from depressions between rows to a sediment pond off the experimental site. This ensures that applied fertilizer was not able to move between plots. A series of 12 rows, hereafter called "plots", were created on the site (Fig. 1). Six of 12 plots remained ungraded without further working. Tops of the remaining 6 plots were leveled using a single pass with the lightest tracked vehicle available, to create a graded surface with minimal compaction (Sweigard et al. 2007).

Experimental design

Plots at one end of the site varied from those at the other end in shade cast by the adjacent forest, and varied somewhat in substrate properties. Therefore, plots were blocked into three replicates of four plots each, in a randomized complete block design. Lime (Liquid Lime Plus, Caudill Seed. Co., Louisville, KY) was applied as a suspension to one randomly selected half of each plot. Liquid lime ($CaCO_3$) rates were calculated based on soil tests to create a neutral soil (5 gal/acre or 46.78 L/Ha). The first liquid lime application was the 2nd of June of 2009, and a second application was made on May 26th of 2010 as soil tests in April showed that pH had returned to levels similar to control plots. Water-soluble fertilizer (20:20:20 N:P:K) was applied to provide nitrogen at a rate of 100 Kg/ha or 400 Kg/ha to 3 randomly selected level plots and 3 ungraded plots. In this way we created 3 replicates of each of 4 treatments: low pH low N (control), low pH high N, neutral pH low N, neutral pH high N. Treatments were applied two weeks before planting in May of 2009. Initial soil tests showed nitrogen levels below detection limits, and previous research has shown very poor early establishment of both trees and ground cover with such low initial nitrogen levels. Therefore a low, rather than zero, nitrogen application was used and considered to be the control.

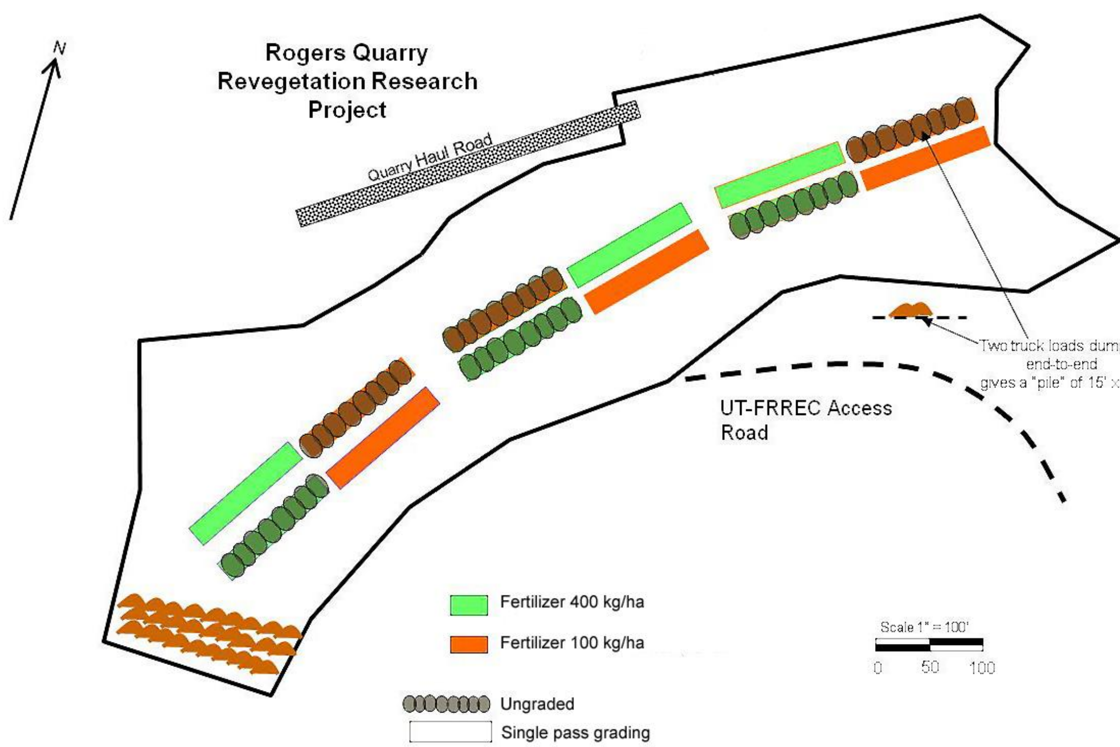

Figure 1. Arrangement of plots and treatments on the Oak Ridge study site.

Three species were selected that are of interest in forest restoration, tolerant of open site conditions, and representative of a range of growth rates and forms. All plants were one-year old bare-root seedlings. White oak (*Quercus alba*) and shortleaf pine (*Pinus echinata*) were provided by the Tennessee State Nursery and American Chestnut (*Castanea dentata*) seedlings were provided by the U.S. Forest Service. Monocultural blocks of each species were planted on a 1.8 x 1.8 m spacing in all combinations of grading, compaction, fertilization, and liming treatments. Seedlings were planted in a grid on graded plots (Fig. 2), while on ungraded plots, monocultural blocks were planted so that 6 seedlings, on the same spacing, face each of the cardinal directions (Fig. 3). No ground cover was planted, and native and exotic herbaceous, shrub, and tree species were allowed to colonize plots from surrounding seed sources.

Figure 2. An ungraded plot, one year after planting.

Figure 3. A graded plot, one year after planting.

Measurements

A composite soil sample comprised of combined subsamples from all plots was obtained to determine overall texture of the substrate. The sample was 66.2% coarse fragments (> 2mm diameter) and 33.8% fines. The Bouyoucos methodology (Day, 1965) was applied, using 3 replicate subsamples, with the finding that fines were composed of 17.81% clay, 5.33% silt and 76.85% sand. According to soil textural classification the overburden is a sandy loam. The soil pH was measured at the beginning of the project (14th of July, 2009), once during the following spring (27th of April, 2010) and again during the second summer (24th of June, 2010). Analysis was performed in triplicate for each sample, which was a composite collected from within each half-plot (treatment unit).

Seedling growth and transpiration were compared between plots with liming and fertilization treatments, with seedling growth measured as increase in height and root collar diameter (RCD) since planting. Seedlings were measured just prior to planting in the last week of May, 2009, and then again in June, 2010. Transpiration was measured with a steady state porometer (model LI-1600 Licor, Inc., Lincoln, NE) during summer (three times, one per month) in oak and chestnut seedlings: 8 seedlings of each species were selected, 4 per half of each plot (lime and no lime treatments) and facing north and south aspects. Transpiration of the uppermost fully expanded leaf was measured between 9:00 am and 12:00 pm.

Due to the large sample size of over 400 seedlings per species, sample points that were greater than 2 standard deviations outside the population were considered to be an error in measurement or recording, and were therefore removed prior to statistical analysis. A general linear model was performed using SPSS 17.0 (SPSS Inc., Chicago, IL) to test for main effects of lime treatment, fertilizer treatment, grading, and aspect, on tree height and RCD for each species. Where significant interactions were found between main effects, a Duncan post-hoc analysis was used to test for differences between treatments. ANOVA repeated measures was utilized to test for treatment effects on leaf transpiration in American chestnut and white oak.

Results and Discussion

Fertilization

The higher rate of fertilization increased the growth of planted tree seedlings. American chestnut and white oak seedlings had significantly greater root collar diameter growth (Fig. 4) and greater mean height growth (Fig. 5) in those treatments with higher fertilizer concentration. A previous greenhouse study (Laroche et al., 1997) also found that fertilization enhanced chestnut seedling performance. The fast growth rate likely makes this species very demanding of nutrients but also able to adapt to low nutrient environments (Latham, 1992). While low fertility did limit growth, this did not appear to result from reduced leaf function, as transpiration rate was not related to fertilization treatment (data not shown).

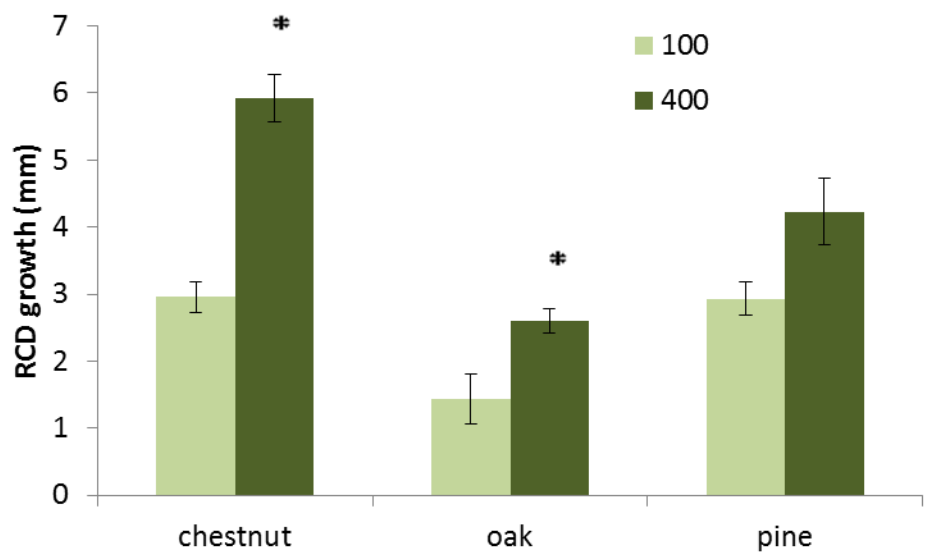

Figure 4. Root collar diameter growth of three species from June 2009 to July 2010, in response to fertilizer treatment at 100 or 400 Kg/ha. Means ± standard errors are shown. * indicates differences between treatments are significant at $p \leq 0.05$.

Fertilization also increased the growth rate of white oak. Oak's pre-formed growth habit may delay or limit its height growth in response to fertilization, therefore several years of data will be required before growth comparisons between the 3 species can be made. However it seems, in contrast to chestnut, increased fertility affected the growth of oak through an increase in leaf function, as was demonstrated by a consistently higher rate of transpiration in the high fertility treatment (Fig. 6). Neither pine nor chestnut transpiration rate (data not shown) was affected by fertilization. A significant, though small, increase was seen in pine height growth in response to fertilization, however pine was more sensitive to pH, as a significant interaction was found between fertilization and lime treatments, as is discussed below.

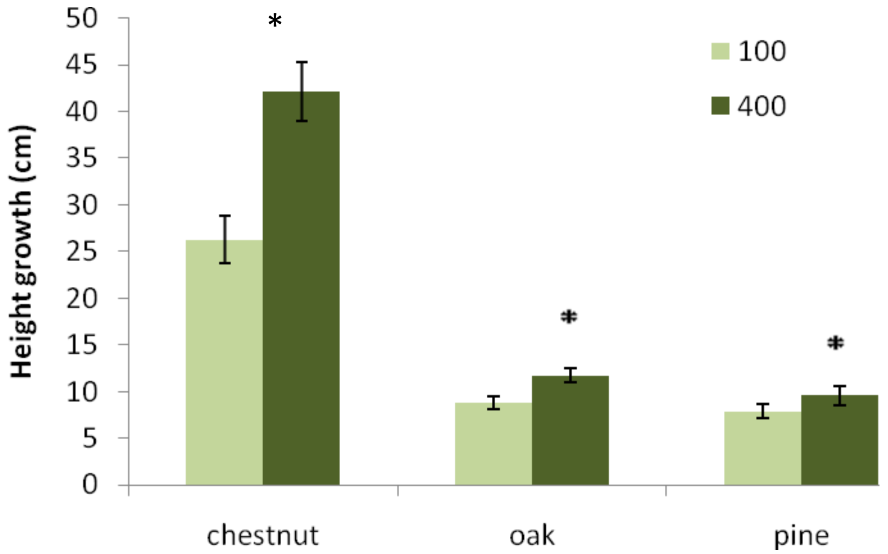

Figure 5. Height growth of three species from June 2009 to July 2010, in response to fertilizer treatment at 100 or 400 Kg/ha. Means ± standard errors are shown. * indicates differences between treatments are significant at $p \leq 0.05$.

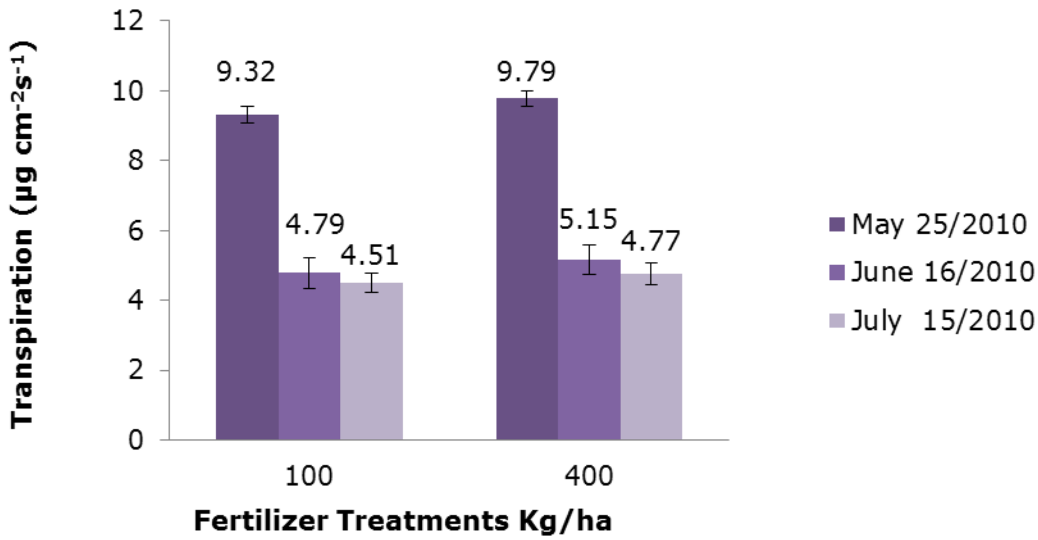

Figure 6. White oak transpiration response to fertilizer treatments in summer 2010. Means ± standard errors are shown. Using a repeated measures design, the difference between treatments is significant at $p \leq 0.05$.

Lime application

Lime treatment had little effect on root collar diameter growth of any of the three species (Fig. 7). Nor did oak or chestnut show any height growth response to lime application (Fig. 8). Messenger (1986) found that a pH range between 4.5 and 6.5 is optimal for white oaks healthy

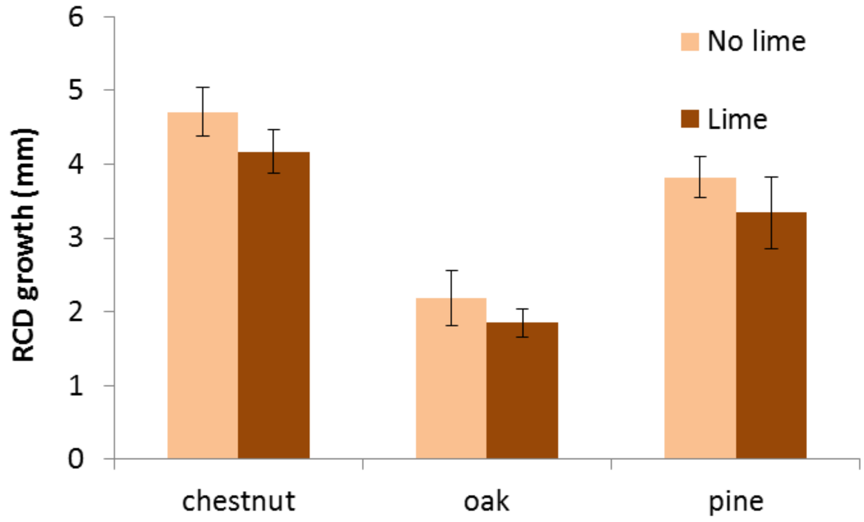

Figure 7. Root collar diameter growth of three species from June 2009 to July 2010, in response to lime application. Means ± standard errors are shown, and no significant differences between treatments were found at $p \leq 0.05$

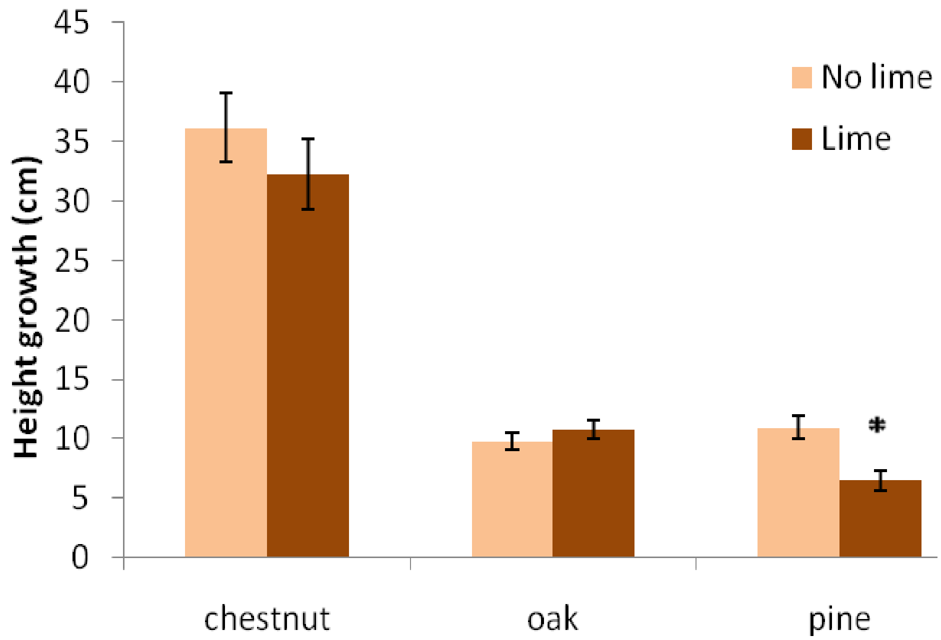

Figure 8. Height growth of three species from June 2009 to July 2010, in response to lime application. Means ± standard errors are shown. * indicates that differences between treatments are significant at $p \leq 0.05$.

development, and both control and limed plots fell within this range. The change in soil pH as a result of lime application was small, 4.97 in control vs. 5.13 in limed plots when averaged across all plots and across the 14 months of study, and although hydrated lime can alter soil pH quickly, the effects are transient. Chestnut's optimal growing conditions are well drained sandy and acidic (pH 4-6) soils (Rhoades, 2007; Tindall et al., 2004), also similar to those on the site. However there is evidence that American chestnut responded positively to lime application; transpiration rate in May was lower in the control than in the limed treatment, but after the second application of lime in June, transpiration rates were significantly higher in this treatment (Fig. 9). The reduction in transpiration rate later in the year may have been the result of more mature leaves (Sobrado, 1994) or weather conditions, however soil temperature and soil moisture were also measured (data not shown) and showed no significant relationship to transpiration rate. A previous study (Rhoades, 2007) found that in sandy loam soils (similar to our study site) when pH and extractable calcium decrease, American chestnut's tendency is to increase in girth;

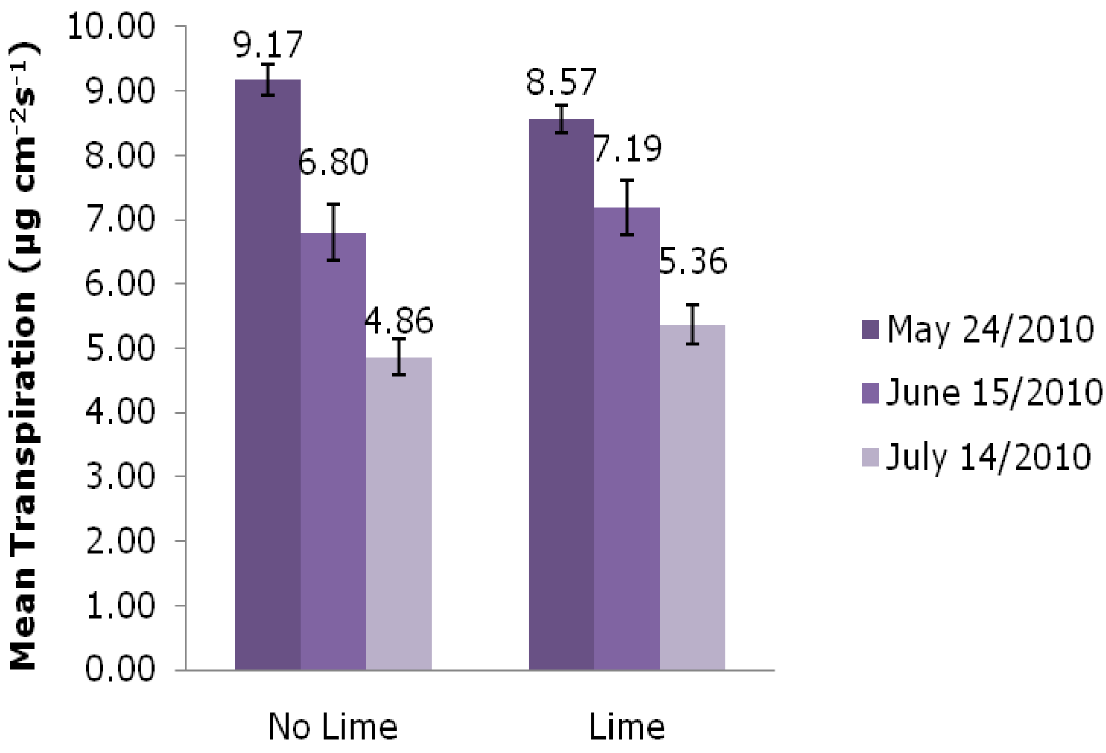

Figure 9. American chestnut transpiration rates in summer of 2010 in response to lime treatments: Means ± standard errors are shown. Interaction between measurement dates and pH treatment is significant at $p \leq 0.05$.

this can be explained by the decrease in base cations from the soil exchange complex and storage in tree biomass. According to this, addition of liquid lime (C_aCO_3) to the substrate may create a transpiration response in chestnuts due to the increase in cation storage in tree biomass, which can enhance water uptake. Laroche and others (1997) found that addition of Ca and Mg increased the growth of chestnuts, showing the deficiency of these two elements in the substratum. On the other hand, in this study the pH of control plots (5.43- 4.47) were in a range closer to optimal soil conditions (Rhoades, 2007; Tindall et al., 2004), which may explain the lack of significant growth response to liming on this site. Neither oak nor pine transpiration rate was affected by lime treatment.

Shortleaf pine had greater height growth in plots where lime was not applied. Growth of the RCD had a significant interaction between lime and fertilization treatments; although seedling growth was greater in unlimed plots, this effect was ameliorated by the addition of a higher fertilizer application (Fig. 10). This result agrees with an earlier experiment (Walker, 2002) in which the application of dolomitic lime was detrimental to growth, increasing mortality and

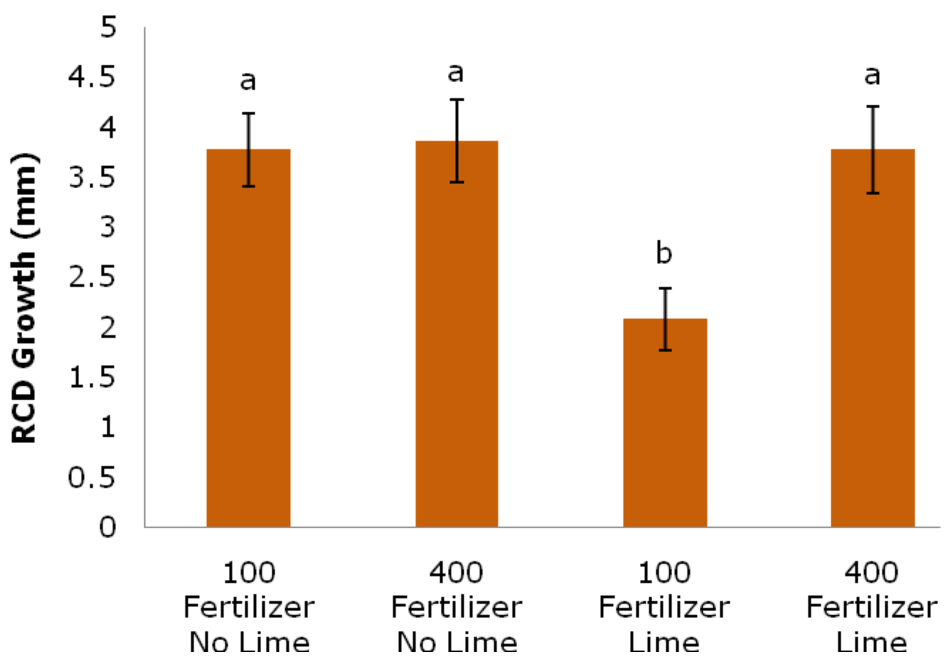

Figure 10. Shortleaf pine RCD growth from June 2009 to July 2010 in response to fertilizer and lime. Means ± standard errors are shown. Different letters indicate a significant difference between treatments at $p \leq 0.05$.

inhibiting seedlings nutrition capacity in Jeffrey pine (*Pinus jeffreyi*). As has been previously demonstrated (Gleeson and Good, 2003), shortleaf pine increases its growth when fertilizer is added to the soil. Chapman (1941) found that this species prefers acidic soils, and it appears that lime application on this site raised soil pH to outside of the optimal range of shortleaf pine.

<u>Grading</u>

The effect of heavy grading on seedling growth has been well documented (Angel et al., 2006). Single-pass grading on our plots left soil that appeared loose and uncompacted as determined by the ease of planting, although we were not able to measure soil density on these plots. Therefore, while this treatment had an effect on tree growth, we cannot state conclusively whether this was due to compaction, topography or most likely, a combination of the two. Both pine and American chestnut seedlings had greater RCD growth in ungraded plots, as compared with graded plots (Fig. 11), while height growth was not affected by grading treatment (Fig. 12).

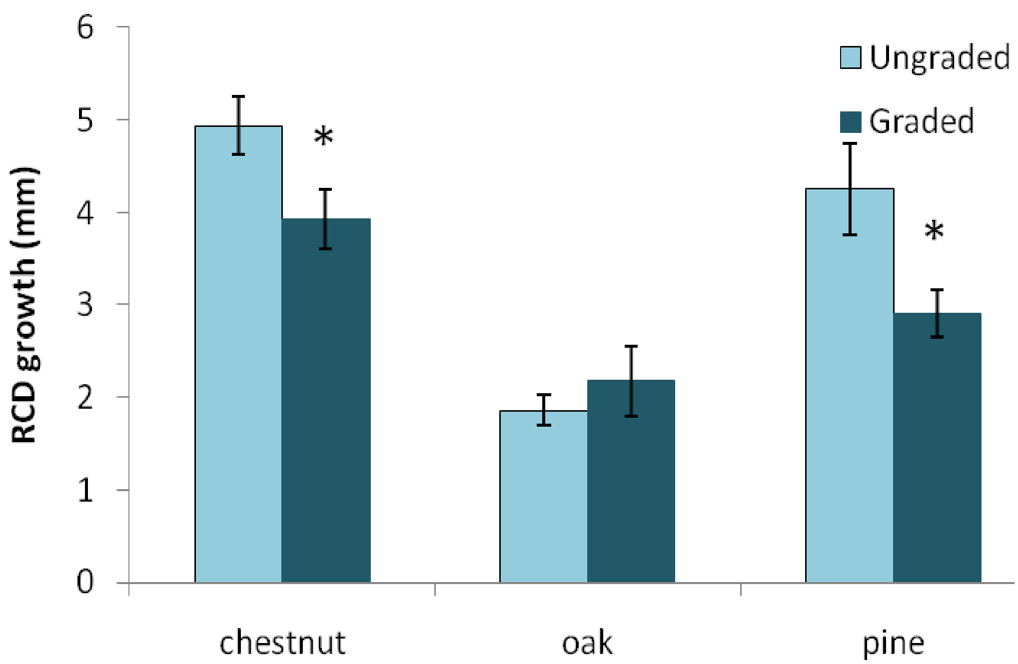

Figure 11. Root collar diameter growth of three species from June 2009 to July 2010, in response to grading. Means ± standard errors are shown. * indicates differences between treatments are significant at $p \leq 0.05$

Chimner and Hart (1996) suggested microtopography is relevant due to its interaction with hydrology to create diverse microhabitats, so it is possible that microhabitats on ungraded plots are preferrable for root development. Average soil temperature over the growing season was very similar for both treatments (21.9 °C), however average soil moisture was lower in ungraded plots

(10.83%) than in graded plots (19.39%), which may explain differences in growth between the two topographies. Height growth shows a similar behavior to RCD growth although there was a significant interaction between grading treatment and the fertilizer applied; the greatest growth was in ungraded plots with higher nutrient concentration.

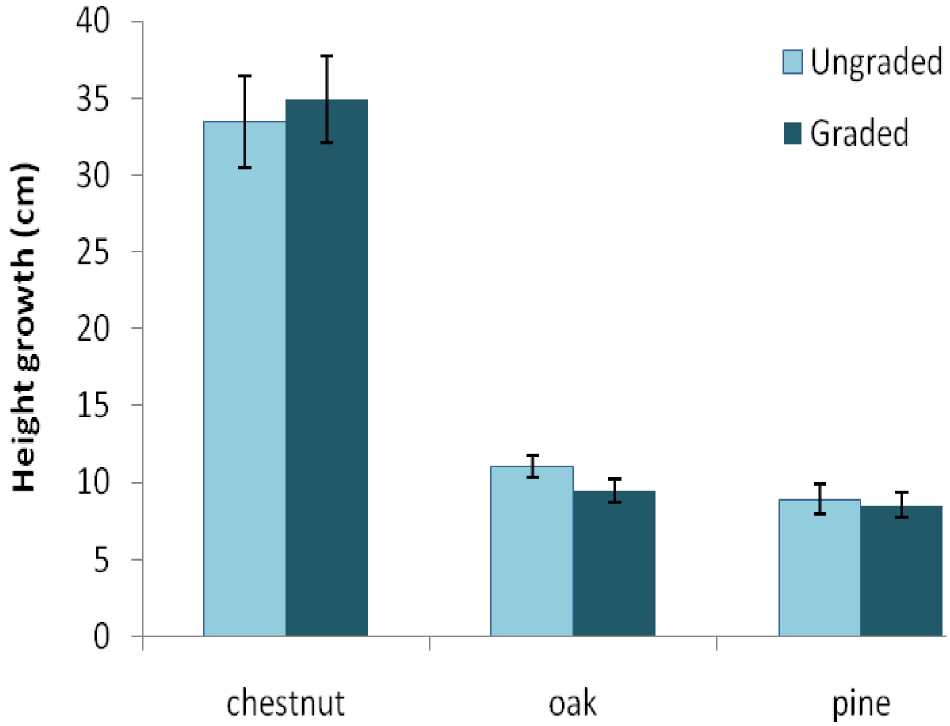

Figure 12. Height growth of three species from June 2009 to July 2010, in response to grading. Means ± standard errors are shown. No significant differences were found between treatments at $p \leq 0.05$.

In several cases, interactions between grading treatments with lime and fertilization treatments were found to affect seedling growth. Chestnuts on ungraded plots with a lower fertilizer application rate had the least height growth, while on graded plots there was little effect of fertilizer concentration (Fig. 13). It is possible that nutrient retention is greater on graded plots. Grading interacted with both lime and fertilization rate in its effect on shortleaf pine root collar diameter growth (Fig. 14). While grading was generally detrimental to pine growth, a higher rate of fertilizer application appeared to overcome this effect.

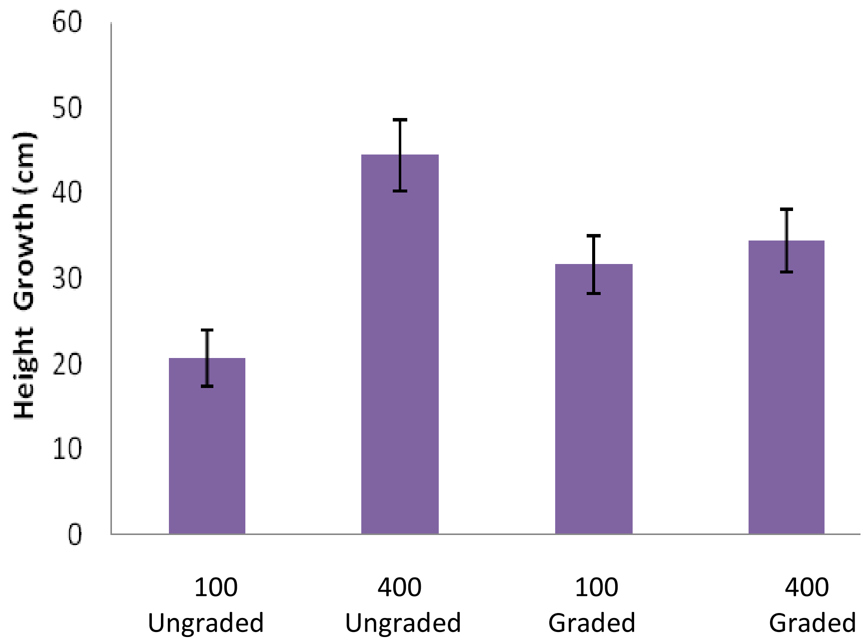

Figure13. Interactions between fertilization level (100 or 400 Kg/ha) and grading treatments on American chestnut height growth from June 2009 to July 2010. Means ± Standard errors are shown.

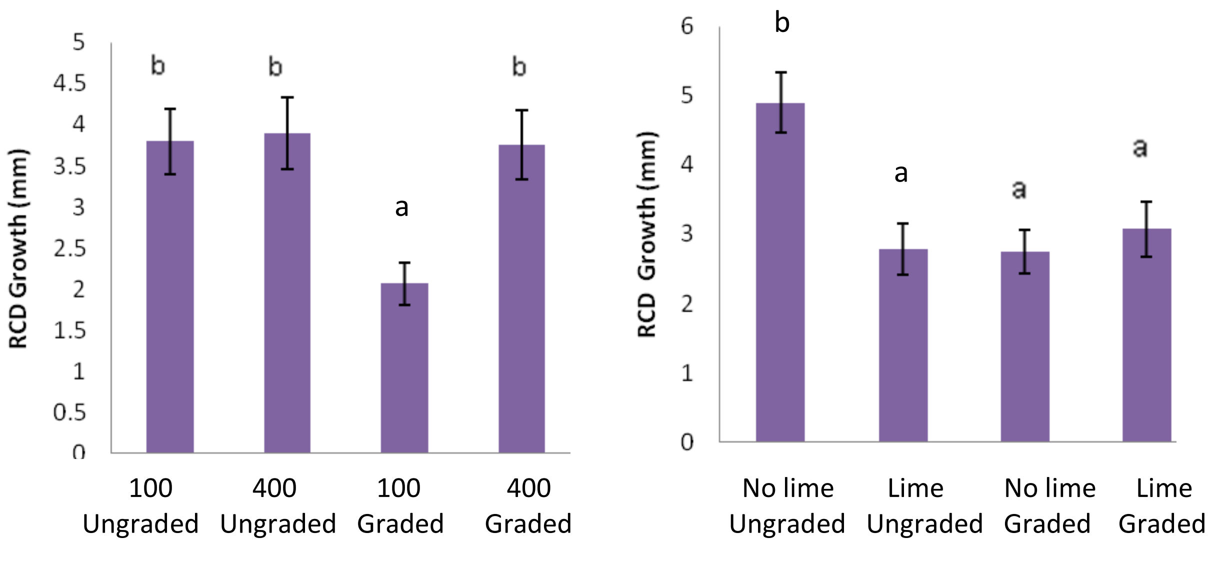

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Figure 14. Interactions between fertilization level (100 or 400 Kg/ha) and grading treatments (left) and between lime and grading treatments (right) on shortleaf pine RCD growth from June 2009 to July 2010. Means ± Standard errors are shown. Different letters indicate a significant difference between treatments at $p \leq 0.05$

Conclusion

All three main factors, grading, fertilization rate, and lime application, and interactions between them played a role in the early growth of planted seedlings. American chestnut prefers well-drained slopes and a high nutrient supply. White oak is relatively insensitive to small changes in soil pH, and site characteristics influenced by grading treatment, at least within the range created within this study, although it did respond to fertilization. Pine was the most sensitive of the three species to factors tested, having a preferance for ungraded, acidic soils. However, it was more tolerant of lime application when provided with a higher rate of fertilization. The identification of microsite preferances, followed by targeted planting to take advantage of those preferences, should aid in the early establishment of seedlings planted on reclaimed mine sites.

Acknowledgements

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