RIPPING COMPACTED MINE SOILS IMPROVED TREE GROWTH 18 YEARS AFTER PLANTING[1]

James A. Burger[2] and Daniel M. Evans

Abstract. Since the implementation of SMCRA, mined land has been heavily graded and much of it has been severely compacted as coal operators attempted to return it to its approximate original contour. Tree survival and growth on compacted mine soils was invariably poor, which compelled mine operators to use non-forestry, post-mining, land reclamation. However, some landowners were interested in post-mining forests for products and services such as carbon sequestration and watershed control. The purpose of our study was to test the effects of ripping mine land after it had been graded and reclaimed using practices common since the implementation of SMCRA in 1978. In 1991, cooperating with a coal operator in Martin County, KY, we created three replications of two site preparation treatments in half-acre plots on level (<5%) and sloping land (40%). The treatments were 1) three grading passes plus tracking (Compacted), and 2) Compacted plus ripping (Ripped). In each of the six plots, three rows of sycamore (*Platanus occidentialis*), sweetgum *Liquidambar styraciflua*), yellow poplar (*Liriodendron tulipifera*), loblolly pine (*Pinus taeda*), and white pine (*Pinus strobus*) seedlings were planted on a 3-m spacing (trees were planted in rips). Tree survival, height, and diameter were measured in the fall of 2009. Average tree survival was 47% and 58% for the compacted and ripped treatments, respectively. Overall tree volume, which is an index of above-ground biomass, was 0.37 and 0.50 m^3 on the standard and ripped treatments, respectively. Ripping significantly improved the growth of all species except white pine, but only 12% of the white pines survived in either treatment. Ripping proved to be an overall beneficial practice; however, it did not fully mitigate the adverse effects of compaction. Tree growth potential on these ripped treatment plots was less than half that of pre-mining capability based on average productivity values listed in the county soil survey for the pre-mining soil type.

Additional Key Words: Appalachian coal fields, carbon sequestration, woody biomass, biofuels.

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Introduction

Many forests planted on coal mined land in the Appalachians and Mid-continent regions prior to the implementation of the Surface Mining Control and Reclamation Act (SMCRA, 1977) in 1978 have grown at rates comparable to pre-mining forests (Ashby, 1996; Rodrigue et al., 2002). Researchers attributed fast growth rates to good overall mine soil quality. High-quality, pre-law mine sites invariably had good spoil physical and chemical properties and were left loose and uncompacted after mining. After the SMCRA was implemented, and prior to the use of the Forestry Reclamation Approach (FRA) (Burger et al., 2005) beginning in 2005, mine soils were commonly compacted during the process of reclamation (Angel et al., 2005). New regulations required the landscape be returned to approximate original contour (AOC), and seeded with grasses and legumes to prevent surface erosion and sedimentation (USDOI, 2003). Common post-mining land uses were hayland/pasture, wildlife habitat, and unmanaged forest land. Regardless of which post-mining land use was selected, reclaimed mined sites were heavily graded by large dozers to achieve an AOC with smooth surfaces on which erosion-control groundcover was seeded. Typical reclamation in the Appalachian region consisted of dozing and trucking backfill spoil materials in place then making multiple grading passes to compact and smooth the surface. Because rain events prior to seeding usually crusted the surface and caused small rills and gullies, seedbed preparation usually consisted of "back-blading" (dozer moving in reverse and dragging the blade) and "tracking in" (dozer tracking up and down slope with blade up) to create shallow cleat indentations perpendicular with the slope to catch and retain groundcover seed that was later sown with a hydroseeder. Tens of thousands of acres of mined land were reclaimed in this way during a 30-year period after the SMCRA was implemented.

During the decades of the 1980s and 90s, researchers reported poor survival of trees planted on post-SMCRA mined land; where trees did survive, they grew poorly (Torbert and Burger, 1990; Kost et al., 1998). Furthermore, few native woody species emerged and grew after their seed was wind-blown or carried by birds onto mined sites (Ashby et al., 1980; Wade, 1994; Holl, 2002). The poor survival, growth, and recruitment were largely attributed to compacted-mine soils and the tenacious groundcover vegetation that tolerated this condition. Mined sites remained in a state of arrested succession covered by grasses and legumes such as tall fescue (*Festuca arundinacea)* and serecia lespedeza (*Lespedeza cuneata*) (Groninger et al., 2007).

Based on their research with the Powell River Project in southwestern Virginia, Burger and Torbert (1992) began recommending different reclamation techniques for post-mining land uses that involved planting woody trees and shrubs. They called this combination of techniques the Forestry Reclamation Approach (Burger et al., 2005). One component of this approach is to dump the final layer of backfill and leave it loose and lightly graded. If a mine soil becomes compacted, ripping, or otherwise breaking up the compacted surface as deeply as possible, is also recommended.

Reforesting mined land reclaimed originally as hayland/pasture or wildlife habitat is becoming a priority for some landowners (Angel et al., 2009). Mined land in a state of arrested succession (Groninger et al., 2007) has little value and does not provide the variety of ecosystem services that productive forests can provide. To successfully reforest these lands, most will require deep tillage for water infiltration and nutrient uptake by deeply rooted trees (Burger and Zipper, 2010). Deep tillage using a variety of ripping and sub-soiling tools is being recommended as a remedy for restoring productivity to compacted mine soils (Sweigard et al., 2007), but the extent to which this expensive, energy-intensive treatment improves tree growth and long-term forest productivity is largely unknown.

Therefore, we revisited a research site established in 1991 that was designed to test the effects of ripping on tree survival and growth. Now, after 18 years of growth, trees have established a growth trajectory so we can determine the extent to which this ripping treatment increased long-term productivity and land capability. We compared survival, biomass production, and site index for five tree species on compacted and ripped mine soils on sloped and flat terrain on a reclaimed mined site in eastern Kentucky.

Methods

Site Selection and Preparation

The study site is located on land mined by Martiki Coal Corporation near Lovely, KY. The site on which the study was established is sloped steeply (40%) for 50 m downhill, then levels out to less than 5%. The site was approximately 500 m along the contour and had been backfilled and graded. It was reclaimed by grading the backfill (three passes) until it was smooth with no rocks or gullies. We laid out twelve 0.2 ha study plots, six on the slope and six on the flat. On March 26, 1991, about six months after backfilling and grading, a final pass with D-9

Caterpillar dozers was used to break up the surface crust on half the plots by back-blading downhill and tracking the entire surface by running up and down the slope until the surface was covered with cleat marks from the dozers' treads. Three plots on the slope and three plots on the flat were ripped with a deep tillage tool (1 m) mounted on a D9 dozer. Rips were created at 3 m intervals. On the level area at the base of the slope, rips were installed perpendicular to the slope. Ripping created a rough surface by pulling up large boulders, opening a furrow, and creating ridges of loose soil aligned with the furrow up and down slope.

Tree Planting

Bare root trees were planted on April 1 and 2, less than one week after ripping the plots. Five species, including white pine (*Pinus strobus*), loblolly pine (*P. taeda*), yellow-poplar (*Liriodendron tulipifera*), sweetgum (*Liquidambar styraciflua*), and American sycamore (*Platanus occidentialis*) were planted. All species were one-year stock except for the white pines, which were two years old. In the Ripped plots, trees were planted in or directly adjacent to the furrows. Trees were planted at a similar spacing on the compacted plots. Height and diameter of all trees were measured after 3, 9, and 18 growing seasons. Tree survival for each measurement period was calculated based on the difference between trees planted and trees found in the plots. A relative index of biomass accumulation was computed as tree height x its stem diameter squared (d^2h) (Avery and Burkhart, 2002).

Ground Cover Establishment

On April 16, two weeks after tree planting, herbaceous groundcover was hydroseeded (Table 1). After the first and third growing seasons, three 30 m transects were established in each plot to measure ground cover. These transects were installed along the contour of each plot, approximately one-fourth, one-half, and three-fourths of the distance from the bottom to top of the slope. At two-foot intervals along transects, ground cover was estimated at 150 points per plot using a sighting tube (Elzinga et al., 1998).

Erosion Measurements

Soil movement from the slope was monitored by measuring the change in the distance between the soil surface and the top of metal rods installed in each plot. Three rows of 10 metal rods (spaced 3 m apart) were installed along the contour of each plot one-fourth, one-half, and three-fourths of the distance from the bottom to the top of each slope. Rods were measured in October after the first and third growing seasons.

Table 1. Ground cover species and seeding rates.

	Application Rate	
Species	(lbs/ac)	(kg/ha)
Winter rye	10	11.2
Perennial ryegrass	5	5.6
Orchard grass	5	5.6
Kobe lespedeza	5	5.6
Appalow lespedeza	5	5.6
Birdsfoot trefoil	5	5.6
Redtop	3	3.4
Weeping lovegrass	3	3.4
Ladino clover	3	3.4
Crown vetch	1	3.4

<u>Data Analysis</u>

Analysis of variance was used to test for differences in ground cover, erosion rate, and tree survival and growth. The Tukey HSD test was used to make multiple comparisons between treatments. All analyses were conducted in SAS 9.1 (SAS, 2004). An $\alpha = 0.1$ was used for all statistical tests. Because of the interest in ripping effects on soil erosion, research emphasis during the first 10 years of the study was placed on data from the plots on the slope; survival was not measured on the flat site. A simple randomized design with three replications was used to test for the effect of Compacted versus Ripped treatments when slope data only were analyzed. Tree growth data from the plots on the flat site were collected only at tree age 18. A split plot design was used to compare tree response between the sloped and flat sites (main plots) and between No Rip and Ripped (subplots).

Results

Erosion, ground cover, and tree response to the Compacted and Ripped treatments on the slope site after one and three years were reported by Torbert and Burger (1994). They observed water runoff during a heavy storm in the early summer of the first year. Surface runoff was rapid from the intensively graded compacted plots. On Ripped plots, water flowed across the surface between rips, but eventually flowed into the ripped surface which prevented runoff and sediment from leaving the plot. After the first year before full ground cover establishment, average erosion as measured by the metal stakes on compacted plots was 1.8 cm (0.72 inches). At an assumed soil bulk density of 1.5 g cm^{-3}, this amounted to 270 metric tons per hectare. Soil erosion from the Ripped plots was negligible at 0.02 cm (0.04 inches), or about 2 metric tons per hectare. Ripping had no adverse effect on total ground cover; both treatments averaged 82% cover. Ripping appeared to increase the proportion of the total cover made up of legumes; however, this difference was not statistically significant (Table 2).

Table 2. Soil erosion during the first year after study plot establishment and percent ground cover after five years on a heavily graded (Compacted) mine soil and one that had been ripped (Ripped).

Treatment	Soil Loss from Slope (cm^3)	Total Cover (%)	Legume Cover (%)
Compacted	1.83a	82a	28a
Ripped	0.02b	82a	45a

After 18 years, survival of the five species varied greatly (Fig. 1). Sycamore survived well at 78%, but sweetgum and loblolly pine did poorly at 47% and 22%, respectively. Yellow poplar and white pine nearly failed at 5% and 2%, respectively. Ripping appeared to improve survival of all species, but due to the very high variability among replicate plots survival was statistically better for the pines only.

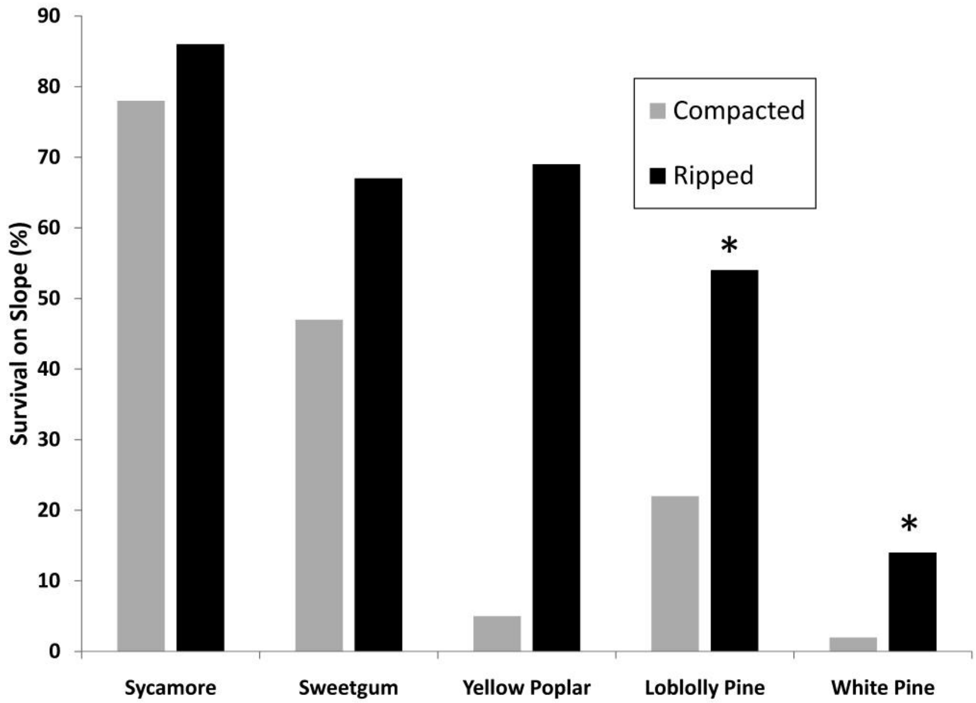

Figure 1. Survival rates after 18 years of five species planted on compacted and ripped mined sites in eastern Kentucky. An asterisk indicates a significant difference in survival between treatments.

A relative comparison of biomass accumulation after 18 years for the five species was made using an index of tree volume (d^2h) (Fig. 2). Overall, the trees grew three times as much on the ripped, flat site compared to the ripped, slope site (0.50 versus 0.16 m^3); and twice as much on the compacted, flat site compared to the compacted, slope site (0.37 versus 0.17); these differences were significant. On the slope site, ripping increased the growth of loblolly pine, but it had little or no effect on the other species. On the flat site, ripping increased the growth of most species, but had the opposite effect on white pine.

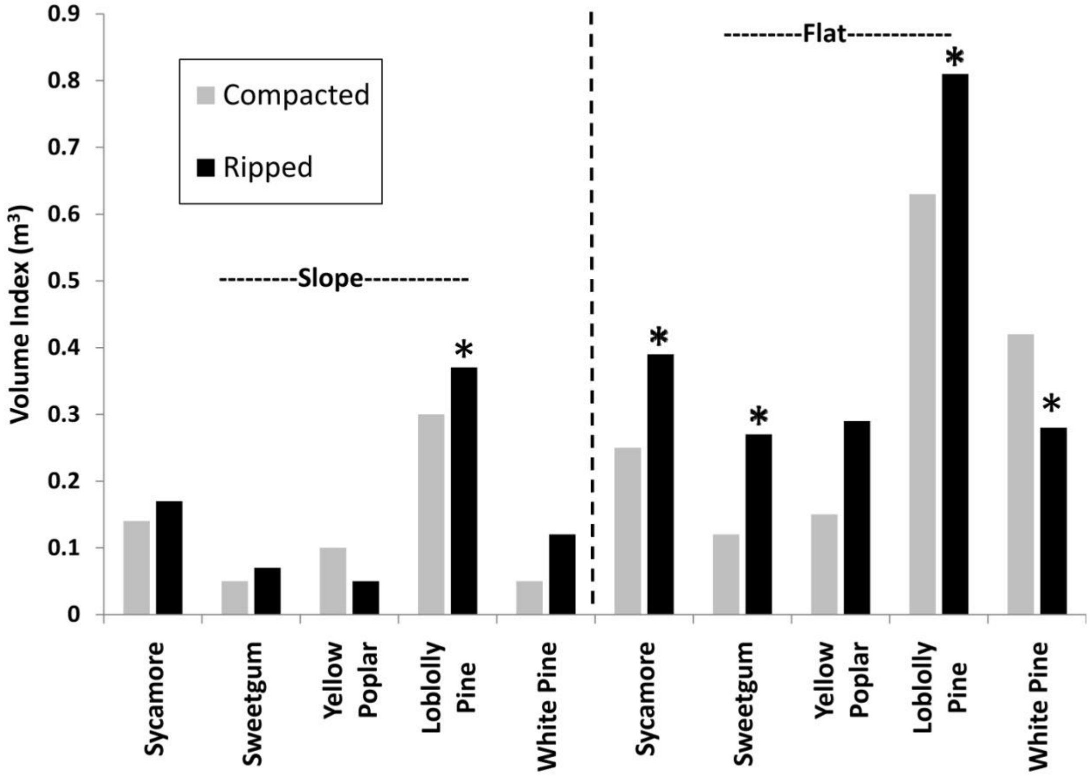

Figure 2. Estimated volume as a relative measure of growth after 18 years for five species planted on compacted and ripped mined sites in eastern Kentucky. An asterisk indicates a significant difference in survival between treatments.

After the third year, survival averaged 60% for all species except white pine, but it decreased considerably on the compacted plots between ages 3 and 9 for all species except sycamore (Fig. 3). Survival on the ripped plots remained relatively constant after the third growing season through age 18. Apparent increases in survival can be due to in-growth, re-sprouting, and variation in tree counting across the 18-year period. Tree height increased at different rates among species (Fig. 3).

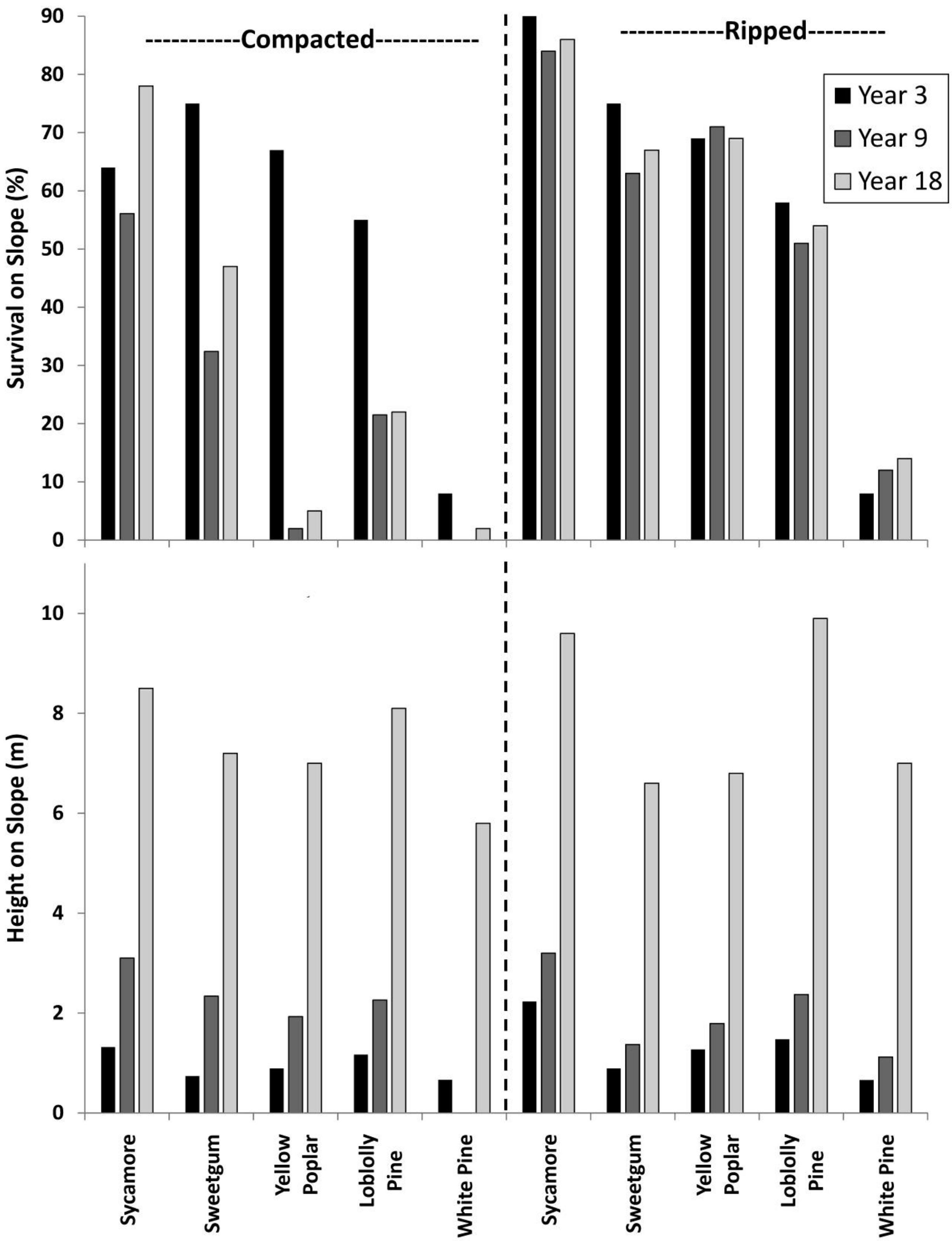

Figure 3. Survival and height of five tree species at ages 3, 9, and 18 on compacted and ripped mined sites.

Yellow poplar is a common native species in the area and an important timber species; therefore, it serves as good indicator of land capability. Site index for yellow poplar was 50 and 55 on the compacted and ripped slope site, respectively, and 58 and 75 on the compacted and ripped flat site, respectively. A weighted yellow poplar site index calculated for all soils in Martin and Lawrence Counties in Kentucky was 89. For soils local to the study site (Rayne, Marrowbone, and Dekalb), the weighted site index was 92.

Discussion

After 18 years, two hardwood species, sweetgum and yellow poplar, and two pine species, loblolly and white pines, planted on a compacted mined site in eastern Kentucky, survived and grew poorly. American sycamore survived reasonably well, but grew poorly. Ripping the tree row into which trees were planted greatly improved the survival of several species. Tree volume growth was also improved by ripping, especially on the relatively flat site included in this study. Several species such as yellow poplar and loblolly pine responded to the ripping treatment more than the others. Our results for this relatively old study site corroborate findings reported by several other researchers who also showed that ripping compacted mined land can improve survival and early growth (Ashby, 1997; Kost et al., 1998). Unlike most of these reports presenting findings for trees only a few years old, our study shows that ripping effects can endure beyond stand closure.

Transplanted tree seedlings are most vulnerable the first several growing seasons after transplanting due to transplanting shock and competition for soil water from herbaceous vegetation. If they survive this early establishment period, they usually survive until stand closure (about age 15) when the weaker trees then succumb to competition from other trees; this is normal self thinning. Trees may not grow well, but they usually survive until this time. This pattern was evident on the ripped plots (Fig. 3). Except for white pine, the other species survived at an average rate of about 60% and maintained that level through age 18. On the compacted, non-ripped plots, all species except sycamore succumbed to additional mortality after the 3-year establishment period. This shows that trees planted on compacted land cannot tolerate the prolonged stress caused by this condition.

Except for loblolly pine, ripping had little effect on volume growth on the slope by age 18. Sloped sites are usually less compacted than flat sites (Andrews et al., 1998) because they generally receive less reclamation traffic from heavy equipment (Sweigard et al., 2007). On the other hand, ripping appeared to improve the growth of most of the species on the flat site except white pine. The flat site had significantly greater overall volume growth than the sloped site, probably due to its depositional position at the toe of the slope. Water running off the surface of the sloped site infiltrated into the flat site.

Site index projections for yellow poplar show that mine site quality of both the sloped and flat sites are far below reference sites for the region, especially on the compacted plots. Yellow poplar site index was 50 and 58 for the compacted sloped and flat sites, respectively, and 55 and 75 for the ripped sloped and flat sites, respectively. Yellow poplar site index for common soil types in the area is 90. This shows that ripping can improve site conditions for tree survival and growth relative to non-ripped compacted sites, but that it does not restore pre-mining capability. Even the best projected site index on this mined site (SI = 75) will produce only half the pre-mining timber value (Probert, 1999; Burger and Fannon, 2009). Ripping is a useful mitigation practice for recovering some pre-mining capability when compaction is unavoidable on some areas of the mined site, but it is no substitute for leaving the mine soil in a loose, uncompacted condition from the outset.

The relatively poor rate of growth even on the best treatment (flat, ripped) compared to pre-mining conditions is likely a function of other site factors in addition to mine soil compaction, including mine soil chemical and biological properties. Most of the species used in this study are native to the area and are adapted to moderately acid, sandy loam soils (pH 5 to 6). The mine soil on this site was blasted siltstone spoil with a pH > 7. A number of reports contain evidence that physical and chemical properties associated with alkaline topsoil substitutes retard tree growth and reduce overall land capability for trees and forestry post-mining land uses (Torbert et al., 1986; Torbert et al., 1990; Emerson et al., 2009). To restore pre-mining forest land capability, both chemical and physical quality of topsoil substitutes must be considered. The results of this field trial show that ripping compacted mine soils will restore some portion of land capability, but only that portion associated with soil density.

Conclusions

Beginning with the implementation of SMCRA in 1978, reclaimed mined land was graded to approximate original contour and sown with herbaceous erosion control ground cover to minimize off-site sedimentation. Achieving AOC and slope stability standards required by the SMCRA usually required multiple grading passes with large dozers which compacted mine soils to considerable depth (Daniels et al., 2001). Trees planted on mined sites reclaimed in this way in both the Appalachian and Mid-continent regions reportedly survived and grew poorly (Ashby, 1997; Kost et al, 1998; Groninger et al. 2006). This study showed that ripping improved survival of most species and improved the growth of several, but ripping alone did not restore pre-mining capability, and it cannot alleviate other growth-limiting factors caused by mining and reclamation. Ripping may alleviate part of the limiting physical condition, but unsuitable topsoil substitutes may be limiting tree growth in other ways. Furthermore, when ripping is applied to compacted sites, it is usually done at tree row spacing, which tills less than half the soil volume that the trees will eventually need to exploit for normal growth.

Ideally, coal operators reclaiming mined land for forestry post-mining uses should avoid compaction whenever possible. When compaction cannot be avoided in places such as temporary roads and parking areas, ripping will restore some land capability, but there should be no expectation that full pre-mining capability will be restored. Recommendations for avoiding compaction (Burger et al., 2005) and mitigating compacted sites (Sweigard et al., 2007) are available at http://arri.osmre.gov/fra.htm .

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