EVALUATION OF LOW SPOIL COMPACTION TECHNIQUES FOR HARDWOOD FOREST ESTABLISHMENT ON AN EASTERN KENTUCKY SURFACE MINE[1]

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Abstract. To return surface mined areas in eastern Kentucky to productive forests, the compaction of mine spoil must be minimized or ameliorated. Four methods to reduce compaction on reclaimed surface mines were compared at the Bent Mountain research site in Pike County, Kentucky. The methods included: single shank ripped spoil, triple shank ripped spoil, excavated spoil, and rough graded spoil. Normally graded spoil was also examined as a control to represent a traditional reclamation practice. A single shank ripper was used in gently sloping areas to a depth of ≈ 2-m, while the triple shank ripper was used primarily on level spoil to a depth of ≈ 1.5-m. Both rippers were pulled with a D-11 dozer. Excavated spoil was created by digging out compacted spoil to a depth of ≈ 1-m and dropping it in place. The end dump or rough graded spoil was created by dumping mixed sandstones and shale spoil from a dump truck to a depth of 2 to 2.5-m followed by minimal grading (single pass) with a D-9 dozer to strike-off the piles. All sites were planted with native hardwood species in 2004. Three plots measuring 50 x 50-m were established within each spoil treatment. All trees within the research plots were tagged and have been examined each year for survival and growth characteristics. Bulk density was also measured annually using a nuclear density probe. Preliminary results show several statistically significant differences in tree height and survival. Survival for white oak (*Quercus alba*) was significantly higher for all reclamation methods compared to the control, and end dump was significantly higher than excavated. Green Ash *(Fraxinus pennsylvanica*) height was significantly greater for all reclamation methods compared to the control, and single shank ripped was significantly higher than all methods. For black locust (*Robinia pseudoacacia*) height and northern red oak (*Quercus rubra*) survival all methods except excavated were significantly greater than the control.

Additional Key Words: hardwood tree performance, compacted spoil, bulk density.

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Introduction

Prior to the Surface Mining Control and Reclamation Act of 1977 (SMCRA), reforestation was the reclamation technique of choice in the eastern United States; however, since its passage a steady decline in the amount, diversity, and productivity of forestland in all coal producing areas of the country has occurred (Burger, 1999). When attempts were made to reforest post-law sites, high seedling mortality, slow growth, and poor production typically occurred due to highly compacted soils with inappropriate chemical characteristics and intense competition from ground cover. The two features of SMCRA that have had the largest effect on the reforestation of surface mined sites are: 1) returning the land to its approximate original contour (AOC) (Torbert et al., 2000; Ashby and Kolar, 1998; Ashby, 1991) and 2) requiring the mining company to reclaim the land to a point where it may "support the uses which it was capable of supporting prior to any mining, or higher or better uses" (United States Congress, 1977).

SMCRA necessitates that mining companies be issued work permits based on several prerequisites: that the company post a performance bond to cover the cost of restoring the site, that the mined land be returned to its approximate original contour (AOC), and that the posted bond money be released only when the final vegetation of the site has been determined to be "successful" (United States Congress, 1977). The post-mining landscape on surface mined lands using mountaintop removal is essentially void of its original relief, and after the coal is removed, bull dozers repeatedly compact the residual spoil material in the process of returning the land to its AOC. Surface mines have been reclaimed in this manner due to the wishes of those interpreting SMCRA, who promote intensive grading for pasture land or industrial land use rather than forestry. As a result, the reclaimed land is so compact that it prohibits root development and tree establishment. Specifically, compacted soil increases bulk density and soil resistance to mechanical penetration, and reduces hydraulic conductivity, as well as air and nutrient flow in the soil (Barnhisel and Massey, 1969).

The second reforestation problem created by SMCRA stems from the former and future uses of land designated for mining. SMCRA requires that mined land be reclaimed to a point where it may "support the uses which it was capable of supporting prior to any mining, or higher or better uses" (United States Congress, 1977). After the passage of SMCRA, coal operators more often chose hayland or wildlife habitat (two of four post mining land uses: cropland, hayland/pastureland, wildlife habitat, or forestland) instead of the original forest for revegetation due to bond release expediency and satisfaction of regulatory requirements concerning sedimentation and erosion control. Burger (1999) reported that 95% of previously forested mined lands are reclaimed to a hayland or wildlife habitat post mining land use, and are abandoned to eventually revert to forests through natural succession (conservatively ~120 years for eastern deciduous forests). Unfortunately, an additional 50-80 years or more are needed before heavy-seeded species, such as oaks and hickories, could become a dominant canopy component.

Until recently, most landowners and mining companies have seen tree planting on post-law mined lands as not economically feasible because of the poor results of early trials (Ashby 1999). In contrast, research has shown that pre-law mined sites can have an equal or higher productivity than that of non-mined forests under certain conditions (Rodrigue et al. 2002; Pope 1989; Ashby 1991). The reclamation of pre-law sites typically resulted in a landscape composed of ridges and troughs, which allowed for less compaction, better rooting capacity, and improved water retention (Zeleznik and Skousen 1996). Based on observations of pre-law sites that are now developing into healthy forests, field studies have been established by researchers since the establishment of SMCRA to uncover the right combination of treatments that will determine the most effective way to re-establish productive forests on these degraded sites.

Although there are formidable obstacles to reforesting reclaimed surface mined sites, promising results from post-law research sites have shown a steady increase during the past 15 years in Appalachia and the Midwest (Angel et al. 2006; Burger and Zipper 2002; Conrad et al. 2002; Rodrigue 2001; Graves et al. 2000; Torbert et al. 2000; Ashby 1999; Thomas 1999; Burger and Torbert 1992). Successful reforestation techniques for surface mined lands continue to be studied, developed, and streamlined, to investigate their effectiveness; however, recommendations for specific spoil treatments that may affect growth trajectories and productivity are still needed. In an effort to gain such knowledge, an experiment was established to examine forest productivity on mine lands as influenced by several low-compaction reclamation techniques.

Methods

Four methods to reduce compaction on reclaimed surface mines were compared at the Bent Mountain research site on Brushy Fork near the community of Meta in Pike County, Kentucky. The methods included: single shank ripped spoil, triple shank ripped spoil, excavated spoil, and rough graded spoil. Normally graded spoil was also examined as a control to represent a traditional reclamation practice. A single shank ripper was used in gently sloping areas to a depth of ≈ 2-m, while the triple shank ripper was used primarily on level spoil to a depth of ≈ 1.5-m. Both rippers were pulled with a D-11 dozer. Excavated spoil was created by digging out compacted spoil to a depth of ≈ 1-m and dropping it in place. The end dump or rough graded spoil was created by dumping mixed sandstones and shale spoil from a dump truck to a depth of 2 to 2.5-m followed by minimal grading (single pass) with a D-9 dozer to strike-off the piles. All sites were planted with native hardwood species in 2004: white oak (*Quercus alba*), red oak (*Quercus rubra*), yellow poplar (*Liriodendron tulipifera*), black locust (*Robinia pseudoacacia*), and green ash (*Fraxinus pennsylvanica*). The trees were randomly mixed in the tree planter's bags to insure distribution throughout the areas planted.

Three 50 x 50-m plots were established on the five different spoil treatments for a total of 15 plots. . The plot sites were chosen at random within the spoil treatments and spaced to limit edge effect when possible. The plot size was chosen to sample an adequate number of trees of each species. During the spring of 2004, all of the trees in the 15 research plots were tagged and measured. Tree number, species and height to the nearest centimeter were recorded. Also recorded was vigor class and distinguishing features that may influence productivity. Measurements were repeated on an annual basis. Bulk density was measured annually on each treatment using a nuclear density probe. Six subplots were randomly selected within each of the three plots located in a specific reclamation method. Bulk density was measured for each subplot at 5, 15, and 30.5 centimeters. A total of 18 bulk densities were taken for each depth and averaged for the reclamation methods. The depth weighted average was then calculated for each reclamation method by weighing each measurement as a proportion of the soil by depth taken.

The data was recorded for the third year of growth in the summer of 2006. I analyzed the height and survival of white oak, red oak, yellow poplar, black locust, and green ash using the

SAS system (2006) with Alpha set at 0.05. These species were either planted in the greatest number or are the most important high value hardwood species. Reclamation treatment effects were analyzed separately for each species. There were three plots within each reclamation method so the plot and replicates were treated as random effects to account for nesting. The proc mixed procedure was used for this variance components model. Tukey's method was used to adjust for the multiple comparisons of the LS means to control type one errors due to unequal variances.

Results and Discussion

Significant differences in both seedling survival and height were observed for the reclamation treatments examined, and the response was species specific. All species, with the exception of white ash, exhibited increased survival in the low compaction treatment plots over that observed in the compacted (control) plots. A general increase in height was also observed in the treatment plots over that observed in the control. A reduction in compaction by the various treatment techniques may be responsible for these results. In 2005, dry bulk density showed a decreasing trend by treatment in the order: triple shank ripper < single shank ripper < end dump < excavated < control (Table 1). In respect to the height and survival some treatments that appear as if they should be significantly different are not due to the unequal sample size and the adjustment this necessitated.

Table 1**.** Bulk density at 5, 15 and 30.5 cm depths in spoils from differing reclamation practices at the Bent Mt. mine in Pike Co. KY.

Treatment	**Year**	**Bulk Density (g cm$^{3\ -1}$)**			
		AVG‡	***5 cm***	***15 cm***	***30.5 cm***
Control	**2004**	***1.77***	1.53	1.72	1.87
Control	**2005**	***1.68***	1.45	1.66	1.77
Excavated	**2004**	***1.66***	1.42	1.61	1.77
Excavated	**2005**	***1.67***	1.47	1.63	1.75
TS Ripper	**2004**	***1.67***	1.41	1.65	1.78
TS Ripper	**2005**	***1.59***	1.32	1.53	1.72
SS Ripper	**2004**	***1.68***	1.48	1.64	1.77
SS Ripper	**2005**	***1.60***	1.38	1.55	1.71
Rough Grade	**2004**	***1.72***	1.48	1.69	1.82
Rough Grade	**2005**	***1.63***	1.44	1.61	1.72

‡Depth weighted average calculated by weighing each measurement as a proportion of the soil by depth taken.

White Oak

There was a general increase in the mean survival rate for white oak as the compaction level was decreased. Both ripping treatments and the end dump treatment exhibited significantly higher survival than the control and excavated treatments (Fig. 1). The end dump also exhibited a significantly higher growth rate over that of the single shank ripper, while the triple shank ripper was not significantly different from either. Seedling height was significantly higher in the end dump treatment versus the excavated plots, but all other treatments were statistically similar (Fig. 1).

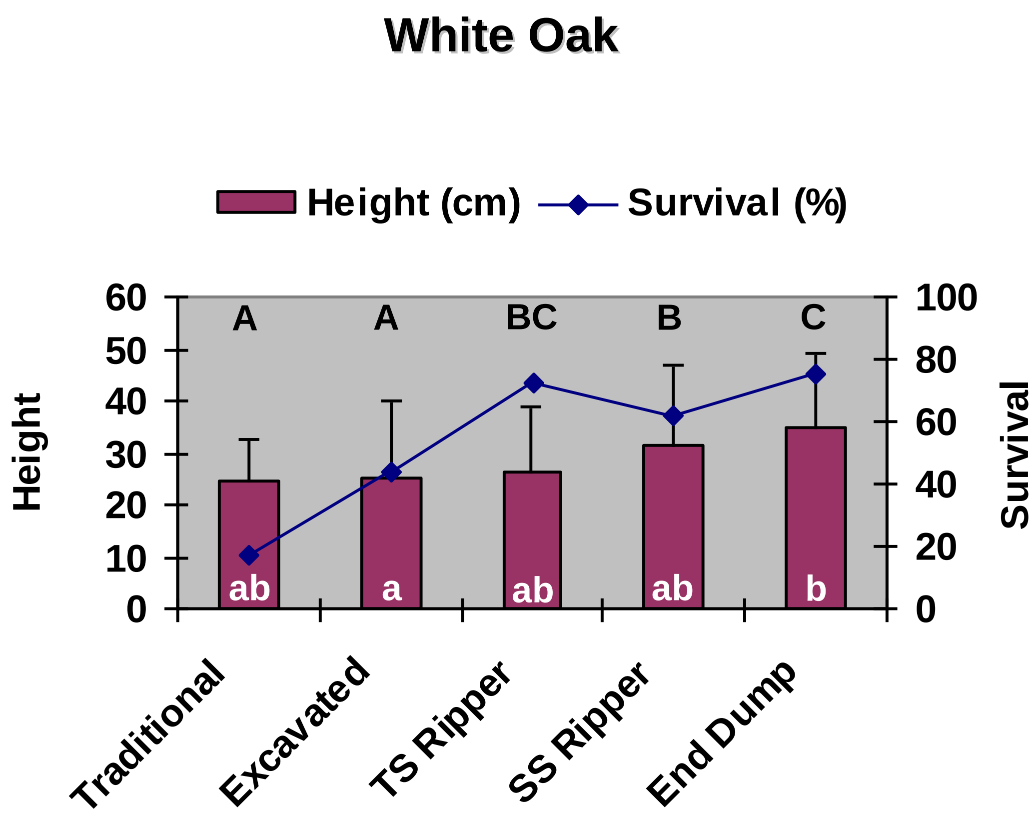

Figure 1. Mean cumulative height (cm) and survival rate for white oak for the four low compaction and control (traditional) treatments. Means with the same letter are not significantly different at the p = 0.05 confidence level. Capital letters refer to statistical relationships for survival, while lower case letters refer to height. Error bars represent one standard deviation.

Northern Red Oak

Northern red oak had a similar response to the low compaction treatments as seen for white oak, where both ripping treatments and the end dump treatment exhibited significantly higher survival than the control and excavated treatments (Fig. 2). Although the response to treatments was similar, red oak survival (0 to 48 % survival) by treatment was lower than that observed for white oak (16 to 75 % survival). Because there was complete mortality of red oak in the control, statistical comparison of height by treatment could not be performed. Regardless, both ripping treatments exhibited similar height measures that were slightly above that of the end dump seedlings and the end dump seedlings were slightly taller than the excavated seedlings (Fig. 2).

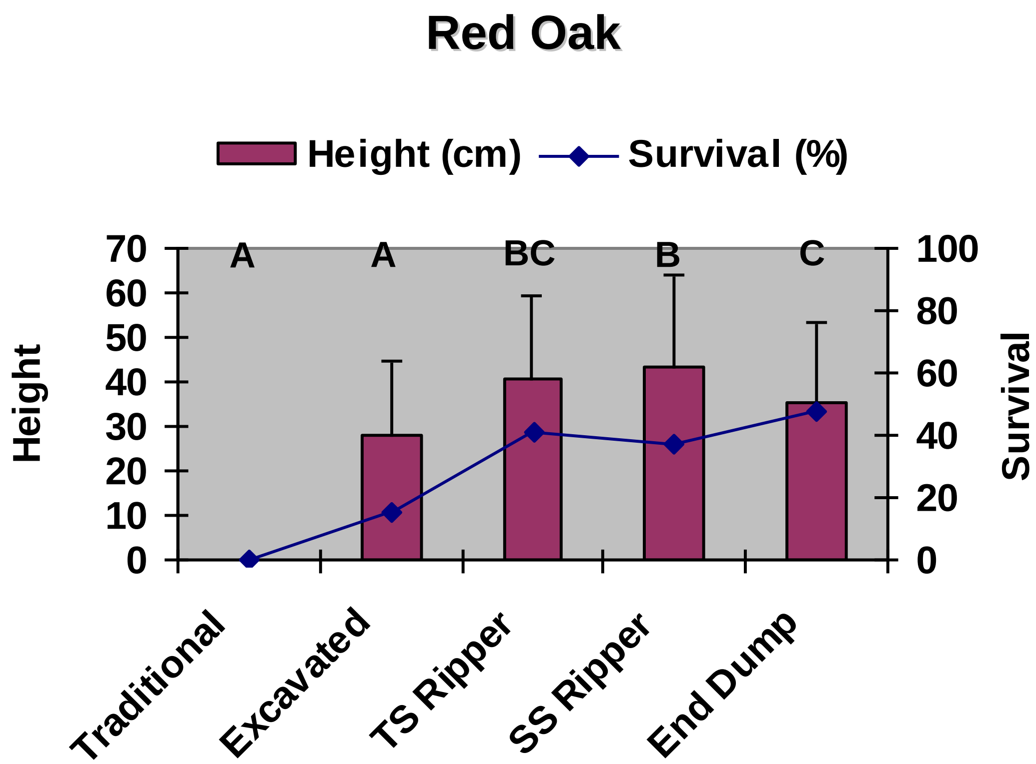

Figure 2. Mean cumulative height (cm) and survival rate for northern red oak for the four low compaction and control (traditional) treatments. Means with the same letter are not significantly different at the p = 0.05 confidence level. Capital letters refer to statistical relationships for survival. Error bars represent one standard deviation.

Yellow Poplar

Survival of yellow poplar was low for all treatments (Fig. 3). The end dump treatment exhibited the highest survival at 43%, while the other treatments exhibited survival rates lower than 25%. Seedling height varied little between the ripped treatments and the end dump treatment, and all three were approximately 10 cm taller than that observed on the excavated plots. As with red oak, all seedlings died on the control plots. These findings are consistent with information our group has generated with respect to the suitability of yellow poplar on surface mine sites (Cotton, 2006). Yellow-poplar grows well in a wide range of soil and climactic conditions but achieves optimal growth in deep, rich, well drained soils of coves and valleys (Wharton and Barbour, 1973). Beck (1990) found exceptional growth of yellow-poplar on alluvial soils bordering streams, on loam soils of mountain coves, on talus slopes below cliffs and bluffs, and on well watered gravelly soils. Further, yellow-poplar cannot tolerate moisture extremes, preferring a moderately moist soil that is well drained and loose textured. The best growth has been observed on north and east aspects, lower slopes, sheltered coves, and on gentle concave slopes (Beck 1990). Unfortunately, the mine sites tend to be drier and less nutrient enriched than soils where yellow poplar naturally exists; thus, the long-term applicability of this species on open mined areas with unweathered spoils, such as that found at Bent Mountain, is questionable.

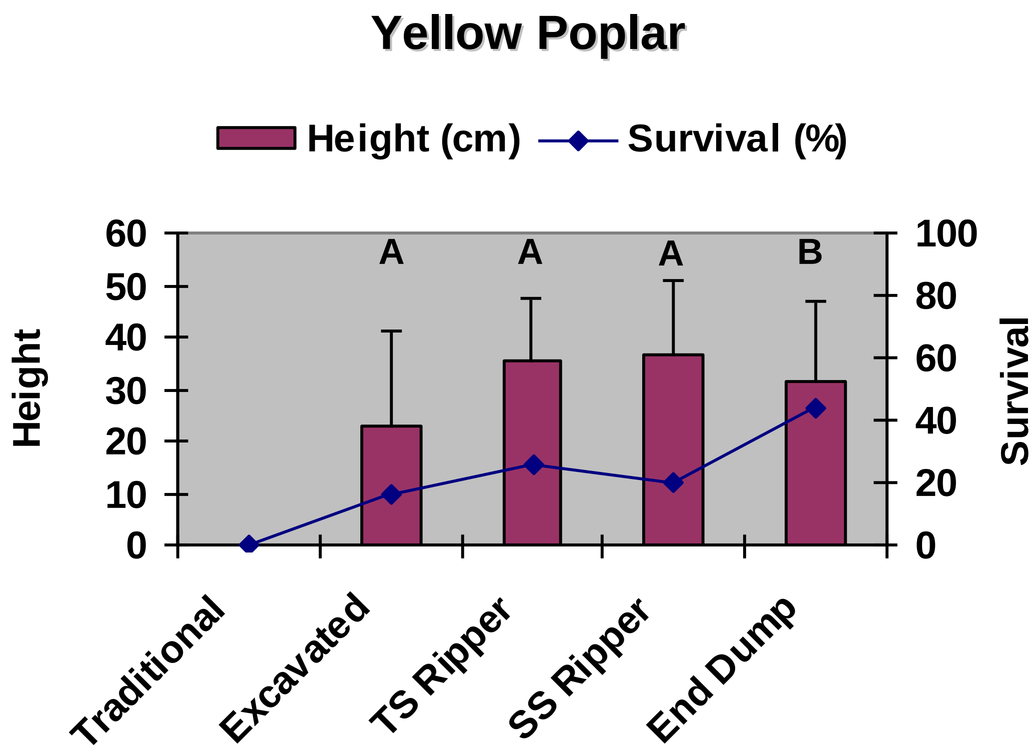

Figure 3. Mean cumulative height (cm) and survival rate for yellow poplar for the four low compaction and control (traditional) treatments. Means with the same letter are not significantly different at the p = 0.05 confidence level. Capital letters refer to statistical relationships for survival. Error bars represent one standard deviation.

Black Locust

Survival for black locust was high (73 to 94%) for all treatments examined (Fig. 4). The end dump and triple shank ripper treatments exhibited significantly higher survival than the control. The excavated and single shank ripper treatments did not differ from the other treatments with respect to survival. Both ripper treatments and the end dump treatment exhibited significantly higher growth than the excavated or control plots (Fig. 4). Black locust also exhibited the highest growth rates of all species examined (≈ 100 cm in three years). Similar results for black locust have been documented and earlier studies identified black locust as a favored site stabilizer because of its nitrogen fixing capability and adaptability to a wide range of soil physical and chemical conditions (Miles et al. 1973). Mixed-species plantings of nitrogen-fixing tree or shrub species with hardwood crop trees are commonly promoted for mine land revegetation (Ashby et al. 1985). In addition, interplanting with controlled densities of black locust seedlings may have potential for increased crop tree growth (Torbert and Burger, 2000). Although difficult to ascertain in these young stands, the success of black locust will likely have a positive impact on the other high value hardwood species planted in the study.

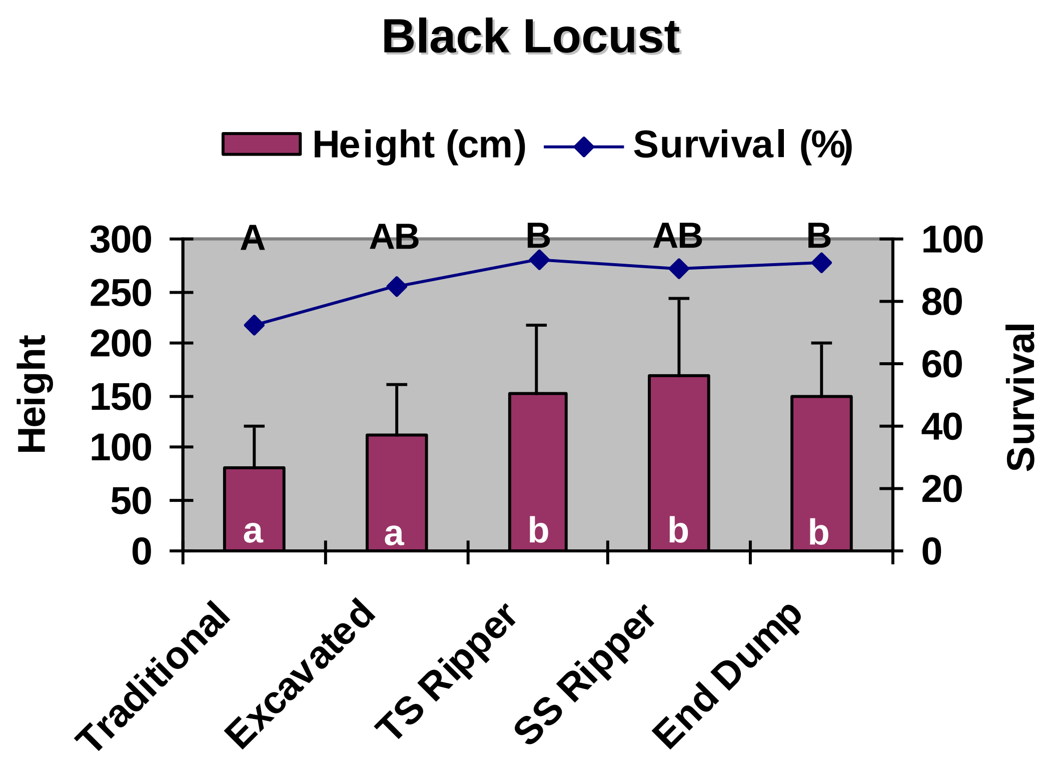

Figure 4. Mean cumulative height (cm) and survival rate for black locust for the four low compaction and control (traditional) treatments. Means with the same letter are not significantly different at the p = 0.05 confidence level. Capital letters refer to statistical relationships for survival, while lower case letters refer to height. Error bars represent one standard deviation.

<u>Green Ash</u>

Survival for green ash was high and similar to that observed for black locust (79 to 93%) for all treatments examined (Fig. 5). Growth was significantly greater in the single shank ripper treatment over all other treatments. Seedling height was significantly lower in the control than all other treatments. Angel et al. (2006) described similar results for white ash in compacted versus uncompacted spoils.

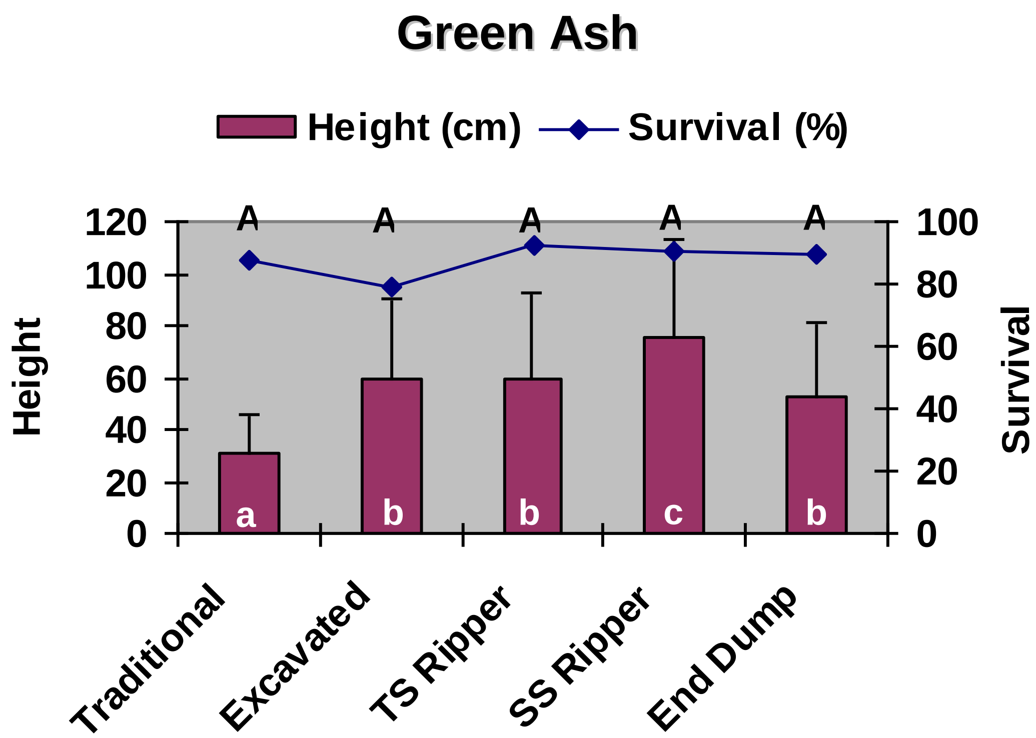

Figure 5. Mean cumulative height (cm) and survival rate for white ash for the four low compaction and control (traditional) treatments. Means with the same letter are not significantly different at the p = 0.05 confidence level. Capital letters refer to statistical relationships for survival, while lower case letters refer to height. Error bars represent one standard deviation.

Conclusions

Hundreds of thousands of acres of Appalachia have been mined and are often reclaimed in a manner that results in compacted land (Rodrigue *et al.* 2002). Using traditional grading procedures, we found reforestation success to be poor. Complete mortality of northern red oak and yellow poplar were observed using traditional AOC reclamation practices and growth was reduced over the other practices examined. The excavated treatment showed some improvement over the traditional reclamation approach, but the procedure was time consuming (approximately 6 to 8 hours per acre using a Caterpillar 330 excavator) and likely not an economically feasible method for reducing compaction. Ripping can alleviate problems associated with compaction and condition the soils sufficiently for highly productive tree growth (Conrad *et al.* 2002). Ashby (1997) found that ripping to a depth of 1.2 meters statistically increased growth over that of non-ripped spoil for 16 tree species examined in a study conducted in Southern Illinois. In both of these studies ripping was performed using either a small dozer (D-8) or tractor and the ripping depth was approximately 1 meter. The Bent Mountain sites were ripped using a D-11 dozer which allowed for penetration to greater depths. In addition, a custom sleeve designed to fit over the single shank ripper resulted in a highly disturbed surface soil condition. With the exception of green ash, growth and survival of species examined did not differ between the two ripping treatments. In addition, both ripping techniques out preformed the excavated and control treatments. As such, ripping shows promise as a method for alleviating compaction on heavily graded mine lands. Loosely dumped and struck off spoil is the reclamation treatment recommended by the Office of Surface Mining's forestry reclamation approach for active surface mines and provided the best results at the Bent Mountain site.

The research at Bent Mountain will continue to provide valuable information on hardwood tree growth in the future. Surface mine operators and regulators will hopefully use this data to promote proper reforestation of active and previously reclaimed surface mines.

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