SURFACE MINE REFORESTATION RESEARCH: EVALUATION OF TREE RESPONSE TO LOW COMPACTION RECLAMATION TECHNIQUES[1]

Patrick N. Angel, Donald H. Graves, Christopher Barton, Richard C. Warner, Paul W. Conrad, Richard J. Sweigard, Carmen Agouridis[2]

Abstract. In 1996, a multidisciplinary group of researchers at the University of Kentucky initiated a study on the Starfire surface mine in eastern Kentucky to evaluate the effects of soil compaction and two organic amendments on the survivability and growth of high value tree species. Three types of prepared rooting medium were examined: compacted spoil, lightly compacted spoil, and uncompacted spoil. The compacted spoil was prepared using normally accepted spoil handling techniques that resulted in a smooth graded surface. The lightly compacted spoil was loose-dumped and struck-off with one or two passes of a bulldozer. The uncompacted spoil was loose-dumped and not further disturbed. In addition, organic amendments (mulches) were evaluated within the three reclamation techniques. The organic amendments used were processed hardwood bark mulch and a combination of straw and horse manure mulch. The following six species of trees were planted: white oak (*Quercus alba*), white ash (*Fraxinus americana*), eastern white pine (*Pinus strobus*), northern red oak (*Quercus rubra*), black walnut (*Juglans nigra*), and yellow poplar (*Liriodendron tulipifera*). Five of the six species, the exception being white ash, showed increased survivability as compaction was minimized. Additionally, the loose-graded techniques led to enhanced growth in height for the seedlings. The addition of organic amendments also showed additional benefit but results varied by species and by treatment. Results definitively show that strike-off and loose-dump techniques improve seedling height and survival. The data also suggest that even a small amount of traffic (i.e., one or two passes per the strike-off method) may result in enough compaction to significantly reduce survival and growth in some species, such as yellow poplar and white pine. In the backfilling and grading process, spoil material should be placed and compacted according to standard engineering practices so that the required stability and approximate original contour is achieved. However, the top 1.2 to 1.8 meters (4 to 6 feet) of material should not be graded or only lightly graded so that it is as uncompacted as possible.

Additional Key Words: tree performance, compacted spoil, mulches, high-value hardwoods.

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[2] Patrick N. Angel is Soil Scientist/Forester, Office of Surface Mining, United States Department of Interior, London, Kentucky 40741, and Graduate Student in Soil Science, University of Kentucky (UK), Lexington, KY 40506. Donald H. Graves Department of Forestry, UK, Christopher Barton, Department of Forestry, UK. Richard C. Warner, Biosystems and Agricultural Engineering, UK. Paul W. Conrad, Department of Mining Engineering, Montana Tech, Butte, MT 59701. Richard J. Sweigard, Mining Engineering, UK. Carmen Agouridis is Engineer Associate, Biosystems and Agricultural Engineering, UK.

Introduction

A reforestation renaissance is currently underway in the eastern United States on surface mines where forestry has become the post mining land use of choice. The federal and state regulatory authorities in the Appalachian coal fields have recognized the many years of lost opportunity for establishing productive and healthy forests on reclaimed surface mines since the implementation of the Surface Mining Control and Reclamation Act of 1977 (SMCRA) (Public Law 95-87 Federal Register 3 Aug 1977, 445-532). A major reforestation initiative has been commenced and many coal mining companies and land owners are responding by planting more trees on their reclaimed land (OSMRE, 2005). The trend towards the restoration of high value tree species on reclaimed coal mines is due primarily to many decades of hard work by reforestation researchers and experts from universities throughout the East and Midwest. However, many unanswered questions remain in regards to preparing mine spoil for reforestation.

After SMCRA was passed, state and federal regulators focused on the stability of reclaimed land created by surface mines at the expense of restoring the forests that were present prior to mining. As a result, excessive soil compaction had become the major impediment to the survival and growth of planted trees seedling. Ashby et al., (1978) determined that uncompacted pre-SMCRA mining sites resulted in some of the most productive areas in Illinois for the growth of such species as yellow-poplar (*Liriodendron tulipifera*), white oak (*Quercus alba*), and black walnut (*Juglans nigra*). Research conducted in Virginia by Burger and Torbert (1992) verified similar results when mine soil is loose dumped without grading and planted to various tree species. Research conducted at the University of Kentucky and by others has clearly demonstrated that typical post-SMCRA grading practices result in excessive compaction which has a very negative effect on both survival and growth of trees (Graves et al., 1995) (Graves et al., 2000) (Conrad et al., 2002).

Mulches are often used in reclaiming surface mined lands. Mulches control erosion until a vegetative cover is in place, supply nutrients to the vegetative cover, protect seeds and seedlings, alleviate compaction, reduce evaporation, and modify extremes in surface soil temperatures (Plass, 1978, Evangelou, 1981). Mulches can be organic, inorganic or a combination of both. Examples of organic mulches include tree bark, wood chips, sawdust, straw, hay, manure, shredded paper, sewage effluent, and ash. Examples of inorganic mulch are shredded plastic and shredded tires. An advantage of organic mulches is that they may deliver some nutrients as decomposition occurs and they are completely biodegradable. Hardwood bark mulch and straw are two types of organic mulches that are recommended for use on surface mined spoil (Evangelou, 1981). Ringe et al. (1989) conducted a study on a surface mine in eastern Kentucky to determine if hardwood bark mulch would improve biomass production of black locust (*Robinia pseudoacacia*) plantations. Biomass production was compared on plots with hardwood bark mulch and fertilizer applied to that of plots that had only fertilizer applied. Plots that had the hardwood bark mulch and fertilizer had significantly higher biomass after seven years than those plots that had only fertilizer applied. The type of mulch used in any particular situation is often based on several factors. The type of mulch used in any particular situation is often based on several factors including cost, availability, and intended post mining land use (Plass, 1978).

Methods

The University of Kentucky is conducting research at the reclaimed Starfire surface mine in eastern Kentucky in order to quantify the impact of various reclamation techniques on reforestation success. Compaction is likely the most important soil physical parameter affecting the survival and productivity of trees on reclaimed mine sites (Graves et al., 1995). Compaction levels are influenced by the type of equipment used on a site and technique of reclamation. The objective of this research project at Starfire was to examine reforestation methods using low-compaction reclamation techniques that may provide a better environment and growing medium for trees over the conventional reclamation techniques practiced under the requirements of SMCRA. In this study, three types of prepared rooting medium were examined: compacted spoil, lightly graded (loose-dumped and struck-off) spoil, and uncompacted (loose-dumped) spoil. In addition, organic supplements (mulches) were evaluated within the three reclamation techniques.

Site design

Starfire is located in eastern Perry County and western Knott County, Kentucky (37° 24″ N, 83° 08′ W). This mine is located in Kentucky's eastern coalfield in the Cumberland Plateau physiographic region which is predominately forested. Starfire, which is approximately five miles northeast of Hazard, Kentucky, has operated as a mountaintop-removal operation since the early 1980's. Multiple coal seams were mined and overburden was removed using both dragline and truck/shovel operations. The thickness of the topsoil covering the site prior to mining was relatively thin; thus, a mixture of nontoxic, non-acidic shale stratum and sandstone in the overburden at the mine was used as a soil substitute material during reclamation. The soil substitute material was transported to its placement location using rock trucks, where it was dumped and graded using dozers.

In 1996 and 1997, nine 1-hm^2 (2.5-acre) reclamation cells were developed at the mine to represent three subsurface treatments: compacted, struck-off, and loose dumped. Each cell was 70 m wide and 155 m long. The cells were constructed on top of mined land that had been reclaimed to hay and pastureland in the late 1980's. Three compacted cells (#7, #8, and #9) were constructed using normally accepted spoil handling techniques that resulted in a smooth graded surface. They serve as the control cells. The remaining six cells (#1 thru #6) were comprised of new spoil material from the mining operation. Large earth moving trucks (Euclids) were used to loose-dump the spoil material in consecutive piles that tightly abutted each other until the entire cell was filled. Three of these loose-dumped cells (#1, #5, and #6) then received the light compaction with a bulldozer (D-8) which struck-off or leveled the tops of the consecutive spoil piles. The final three loose-dumped cells (#2, #3, and #4) were not further disturbed and represent the uncompacted treatment.

The resulting micro-topography of the nine cells varies from extremely smooth to extremely rough. The three cells containing the compacted spoil are smooth and relatively level with no boulders and very little surface variation. The three cells containing the lightly graded (struck-off) spoil are relatively flat with small undulations near the bases of where the spoil piles were loose-dumped. These light compaction cells have more surface variation than the compacted cells. The three cells containing the loose-dumped, uncompacted treatment exhibit the highest surface variation. These cells are extremely rough and are characterized by unleveled spoil piles with high tops and low depressions with large boulders interspersed.

The surface treatments involved applications of processed hardwood bark mulch to three cells (#3, #6, and #8) and a combination of straw and horse manure mulch to three cells (#4, #5, and #7). The rate of application for both types of mulch was 125 ton ha^{-1} (45 cu yd $acre^{-1}$). The remaining cells (#1, #2, and #9) received no mulch and these serve as the controls.

The construction of the nine reclamation cells resulted in a modified completely randomized plot design consisting of three subsurface treatments (blocks) and three duplicated surface amendments (treatments) on the survival and growth of seven native high value tree species. The three duplicated surface amendments (treatments) were applied randomly to the three subsurface treatments (blocks). Independent variables were compaction level, mulch application, and tree species. Dependent variables were percent survival and height growth. The randomization was implemented so that potential bias associated with non-uniformity of the geochemistry of the mine's surface spoil would be equally distributed between treatments. The nine cells were distributed across the mine in a random fashion based on the mine operators decisions. All cells are within approximately one kilometer of each other.

Although the study design was pseudo-replicated (Hurlburt 1984) by block, testing the significance of treatments was possible. Unfortunately, the installation of the nine reclamation cells spanned a period of two years (1996 and 1997) because of the size and the complexity of the construction of the cells and difficulties in coordinating the mining method of operation and the reclamation in a contemporaneous manner. Cells #7 and #8 were constructed and planted in time for the 1996 planting season. Cells #1, #2, #3, #4, #5, #6, and #9 were installed and planted in 1997. To address the problem of different ages between the two groups of cells, 2003 data were used for cells #7 and #8, and 2004 data were used for Cells #1, #2, #3, #4, #5, #6, and #9. There were no large differences in local weather between the two years of planting.

The following six bare-root tree species were planted by professional tree planters in February of 1996 and 1997: eastern white pine (*Pinus strobus*), white ash (*Fraxinus americana*), black walnut, yellow poplar, white oak, and northern red oak (*Quercus rubra*). The six species were one year old bare root tree seedlings (1-0), purchased from the Kentucky Division of Forestry's tree nursery in Morgan County, Kentucky. A seventh species, Royal paulownia (*Paulownia tomentosa*), was also planted in the reclamation cells at a later date from containerized stock and will not be discussed in this paper. Each reclamation cell is comprised of twenty-one 210.04 hm^2 (0.1-acre) growth plots. The plots measure 20 m x 20 m and one corner was permanently marked with rebar and metal tags identifying plot number and species planted within the plot. Each tree species was randomly allotted to three plots (three replications) within each reclamation cell. Tree seedlings were planted on 1.8- x 1.8-m (6- x 6-ft) spacing, providing 121 trees in each growth plot. The growth plots are separated by 3-m (10-ft) wide alleyways, which provide access to the plots without damaging the growing trees. All reclamation cells were seeded with a mixture of slow-establishing, low-stature, non-competitive grasses and legumes. The grass and legume mixture consisted of annual rye (*Secale cereale*), perennial rye (*Lolium perenne*), orchard grass (*Dactyis glomerata*), birdsfoot trefoil (*Lotus corniculatus*), and Appalow lespedeza (*Serecia lespedeza*, var. Appalow) at the following rates of application: 33.61 kg ha^{-1} for the annual rye and 5.61 kg ha^{-1} for each of the other species.

Over the past ten years, aggressive and highly competitive grasses and legumes, other than those originally seeded, have invaded the plots. It is speculated that many of these species were introduced to the reclamation cells with the straw and horse manure mulch. Volunteer species include serecia lespedeza (*Serecia lespedeza*), Kentucky 31 fescue (*Festuca arundincerea*), and yellow sweet clover (*Melilotus officinalis*) and white sweet clover (*Melilotus alba*). Also, appreciable amounts of sycamore (*Platanus occidentalis*), black locust (*Robinia pseudoacacia*), yellow birch (*Betula alleghaniensis*) and other tree species seeded in on their own.

Data collection

Tree-survival, tree-growth, and soil-compaction data are collected each year from the reclamation cells. The compaction data collected includes mechanical-resistance data (soil strength) using a tractor mounted cone penetrometer, and dry bulk density using a duel-probe nuclear density probe. Further detail on methodologies used for characterizing the spoil physical properties has been described by Conrad et al., (2002).

Seedling surveys involved counting the number of each surviving tree species, and measuring the cumulative height and diameter in centimeters of each tree. Tree survival percentages are calculated by dividing the number of live trees measured in each plot by the number of trees originally planted in the plots.

Survival data of the seedlings were analyzed with repeated-measures logistic regression models (PROC GENMOD). The models included all main-effects and two-way interactions, with survival as the dependent variable, and subsurface (blocks) and surface (treatments) as the independent variables. Probabilities of seedling survival were calculated by back transformation of the least-squares mean (LSM) from the logistical models $(e^{LSM})/(1 + e^{LSM})$. Height measurements for 8 year old seedlings were analyzed with linear regression models (PROC MIXED). The models included all main-effects and two-way interactions, with seedling height as the dependent variable and subsurface and surface treatments as the independent variables. Statistical significance was established were $P < 0.05$ in all cases. All statistical models were performed using SAS (SAS, 1999).

Results

Significant differences in both seedling survival and height were observed for the subsurface reclamation treatments examined, and the response was species specific (Table 1). All species exhibited increased growth in the lightly compacted and uncompacted treatment plots over that observed in the compacted plots. White ash, white pine, black walnut and yellow poplar also exhibited a significant increase in height in the uncompacted plots over that observed in the strike-off treatment. Survival statistics between the compacted treatment and others were similar to that observed for height for all species except white ash, which did not deviate between the subsurface treatments. Survival of white oak, white pine, red oak and yellow poplar was further enhanced in the uncompacted treatment over that of the strike-off treatment. The reduction in compaction by the various techniques is likely responsible for these results. Dry bulk density showed a decreasing trend by subsurface treatment in the order: compacted > strike-off > uncompacted (loose-dump) (Table 2). Depth to resistance increased in a similar manner. Conrad et al. (2002) reported similar findings for these plots at year 3-4.

Table 1. Mean survival and height for eight year old trees as influenced by subsurface reclamation treatment at the Starfire research complex. Means with the same letter are not significantly different.

Method	White Oak	White Ash	White Pine	Red Oak	Black Walnut	Yellow Poplar
			Survival (%)			
Compact	21 (a)	80 (a)	3 (a)	18 (a)	18 (a)	10 (a)
Strike-off	69 (b)	81 (a)	50 (b)	64 (b)	55 (b)	52 (b)
Loose-dump	81 (c)	82 (a)	82 (c)	82 (c)	68 (b)	80 (c)
			Height (cm)			
Compact	63 (a)	104 (a)	87 (a)	93 (a)	58 (a)	125 (a)
Strike-off	197 (b)	236 (b)	307 (b)	242 (b)	116 (b)	203 (b)
Loose-dump	217 (b)	308 (c)	431 (c)	278 (b)	184 (c)	276 (c)

†Surface treatments pooled to examine subsurface effects; n = 1089 seedlings per subsurface treatment and species.

Table 2. Mean dry bulk density and depth to refusal levels as influenced by subsurface reclamation treatment at the Starfire research complex.†

Method	Dry Bulk Density ($g\ cm^{-3}$)	Depth to Refusal (cm)
Compact	1.74	16.1
Strike-Off	1.67	23.8
Loose-dump	1.64	25.0

†Data averages for the period 1998-2001.

Results from the surface treatments, both within and among the subsurface treatments, varied widely (Fig. 1 – 6). The following sections provide detail on these findings for the individual species examined.

White Oak

There is a general increase in the mean survival rate for white oak as the compaction level was decreased. All three subsurface treatments are significantly different from each other (Table 1). Loose-dumped plots did significantly better than strike-off plots, and strike-off plots did significantly better than the compacted plots. The survival rate of white oak in the loose-dumped plots was 81%. There were no significant differences between straw/manure mulch and hardwood bark mulch in survival on both the loose-dumped plots and the strike-off plots (Fig. 1). On the compacted plots however, there is a reduction in the survival from 40% in the plots that received no mulch treatment to nearly 0% in those plots that were mulched with straw and manure. One possible explanation is that for the compacted plots, the “fertilizer” effect of the straw and manure stimulated the grasses and legumes competing with the trees to the point that tree survival was reduced.

Table 1 shows the impact that compaction has on growth in height for white oak. Although little difference exists between the loose-dump and strike-off plots, there is a significant difference in height between those two reclamation techniques compared to the compacted plots. Further, although there appears to be little difference between the three surface treatments in the compacted plots, there are significant differences in the three surface treatments in both the strike-off and the loose-dumped plots (Fig. 1). In the plots with the least compaction, height growth for white oak is greatest for straw and manure mulch, followed by hardwood bark mulch, and the no mulch application produced the least height growth. All three surface treatments follow the same trend as for survival in both the strike-off and loose-dumped plots.

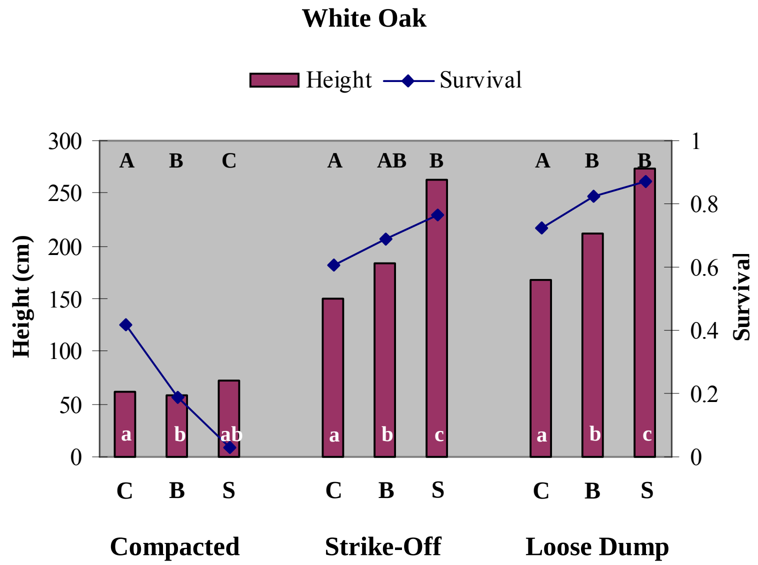

Figure 1. Mean cumulative height (cm) and survival rate for white oak for the three surface treatments (C = control; B = bark mulch; S = straw/manure mulch) and the three subsurface treatments (Compacted; Strike-off; Loose-dump). Means with the same letter are not significantly different at the p = 0.05 confidence level. Capital letters refer to statistical relationships for survival, while lower case letters refer to height.

<u>White Ash</u>

White ash survives equally well on all compaction levels. All three subsurface treatments are not significantly different from each other to mean survival (Table 1). The survival rate on the loose-dumped, strike-off, and compacted plots were essentially the same for this species (82%, 81%, and 80% respectively). In regards to the effect of the surface treatments on the survival of white ash, there may be some reduction in survival due to the fertilizer effect of the straw and manure mulch similar to that speculated for white oak in the compacted cells and strike-off cells (Fig. 2).

Table 1 also demonstrates the impact that compaction has on growth in height for white ash. Significant differences exist for all three subsurface treatments. Height of white ash is best on the loose-dumped plots, followed by the strike-off plots, and least on the compacted plots. Although white ash is surviving on the compacted plots, it is not growing to its full potential. The mean height for white ash on the compacted plots is 104 cm while on the loose-dumped plots it is nearly three times taller (308 cm). Results for the effect of the surface treatments on height of white ash, straw and manure mulch resulted in the best growth, hardwood bark resulted in the second best, and the no mulch treatment being the least best (Fig. 2).

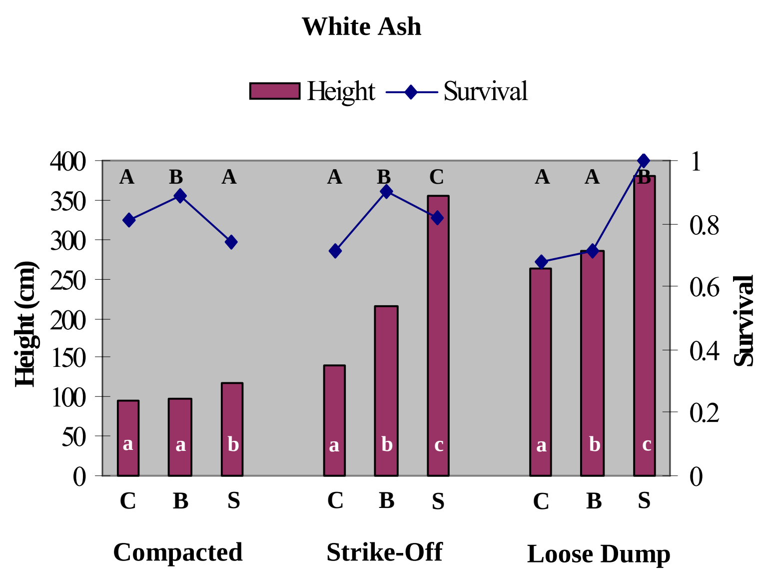

Figure 2. Mean cumulative height (cm) and survival rate for white ash for the three surface treatments (C = control; B = bark mulch; S = straw/manure mulch) and the three subsurface treatments (Compacted; Strike-off; Loose-dump). Means with the same letter are not significantly different at the p = 0.05 confidence level. Capital letters refer to statistical relationships for survival, while lower case letters refer to height.

White Pine

White pine was planted as a "marker" species to relate the work at Starfire to previous research performed by Virginia Polytechnic Institute (Burger and Torbert, 1992). Table 1 shows there is a significant increase in mean survival for white pine as the compaction level decreased, with loose-dumped plots performing significantly better than strike-off plots, and strike-off plots performing significantly better than the compacted plots. The survival rate of white pine in the compacted plots was the lowest for all species (3%). On the other hand, the survival rate of white pine in the loose-dumped plots was 82%. The effect of the surface treatments on the survival of white pine showed there may be some reduction in survival with the straw and manure mulch (Fig. 3).

The growth in height exhibited by white pine on both the loose-dumped and strike-off plots has been good compared to the compacted plots. The mean height for the loose-dumped plots was 431 cm and the mean height for the strike-off plots was 307 cm. This represents the best growth in height for all species. Significant differences were seen between all three subsurface plots (Table 1). Growth in height where straw and manure mulch was applied is better than the other two surface treatments in the strike-off and loose dump cells (Fig. 3). In these same cells, white pine height for the no mulch treatment and the hardwood bark mulch treatment are about the same. For the compacted plots, growth in height was better on the no mulch treatment, and less on the hardwood bark plots, and lowest on the straw and manure plots.

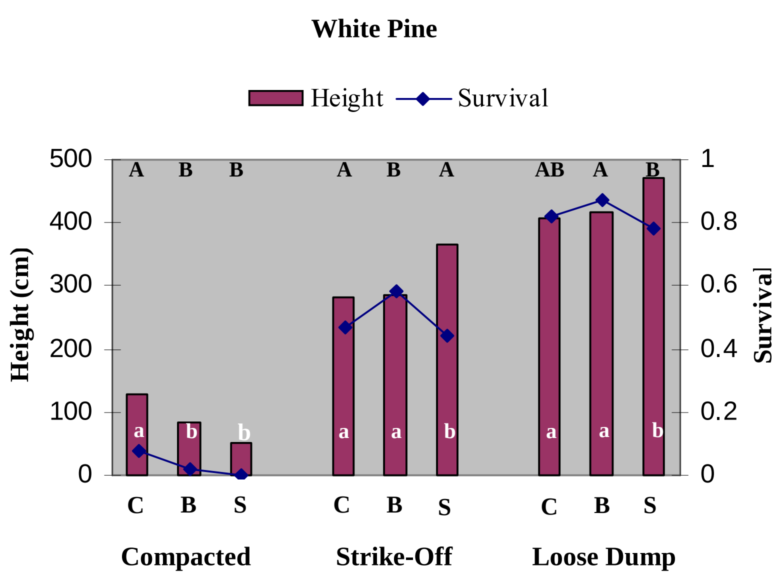

Figure 3. Mean cumulative height (cm) and survival rate for white pine for the three surface treatments (C = control; B = bark mulch; S = straw/manure mulch) and the three subsurface treatments (Compacted; Strike-off; Loose-dump). Means with the same letter are not significantly different at the p = 0.05 confidence level. Capital letters refer to statistical relationships for survival, while lower case letters refer to height.

<u>Northern Red Oak</u>

There is a general increase in the mean survival rate for northern red oak as the compaction level decreased. All three subsurface treatments are significantly different from each other (Table 1). Loose-dumped plots did significantly better than strike-off plots, and strike-off plots did significantly better than the compacted plots. The survival rate of northern red oak in the loose-dumped plots was 82%. A significant difference was detected in the survival of northern red oak for all three surface treatments in the loose-dumped plots (Fig. 4). Straw/manure mulch performed better than hardwood bark mulch, and hardwood bark mulch performed better than the control. As with other species, the survival of northern red oak may be reduced by the straw/manure mulch on the compacted and struck-off plots.

In regards to growth in height for northern red oak, there were no significant differences between the loose-dumped and strike-off plots, but there was a difference between those two plots and the compacted plots (Table 1). Also, growth in height of northern red oak appears to be enhanced in the strike-off and compacted plots that received straw and manure mulch (Fig. 4). Otherwise, the loose-dumped plots followed the usual trend where height was greatest with straw/manure and least with no mulch.

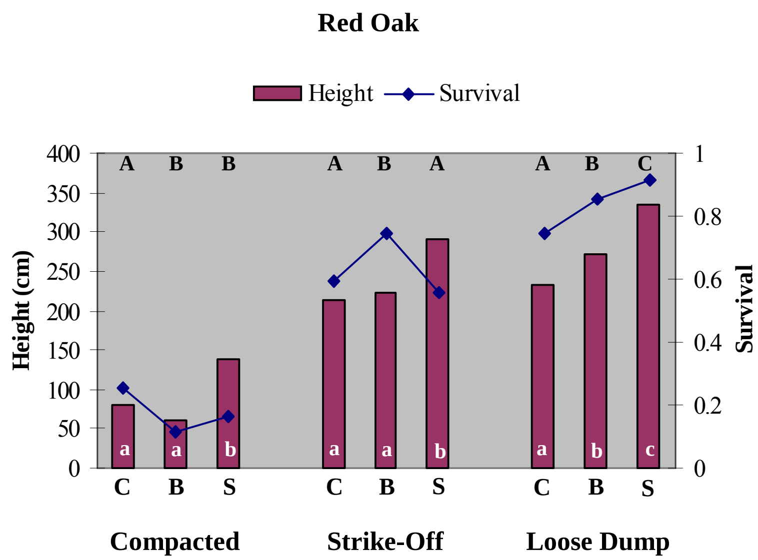

Figure 4. Mean cumulative height (cm) and survival rate for northern red oak for the three surface treatments (C = control; B = bark mulch; S = straw/manure mulch) and the three subsurface treatments (Compacted; Strike-off; Loose-dump). Means with the same letter are not significantly different at the p = 0.05 confidence level. Capital letters refer to statistical relationships for survival, while lower case letters refer to height.

<u>Black Walnut</u>

The black walnut seedlings were unusually large when planted, and as a result, tree planters had difficulty creating a planting hole in the spoil big enough to accommodate the roots. As such, extensive root and stem pruning was performed which may have affected initial growth and survival rates. By the second and third years it was obvious that some of the seedlings had experienced considerable dieback and negative growth rates were observed (Graves, *per comm.*).

Although no significant difference exists in mean survival between the loose-dump and strike-off plots, there is a significant difference in mean survival between those two reclamation techniques and the compacted plots for black walnut (Table 1). The effects of the surface treatments on survival for black walnut are mixed (Fig. 5). First, there is no significant difference in the three surface treatments on survival for the loose-dumped plots. Second, there is a strong difference between hardwood bark mulch and the other two surface treatments for the strike-off plots. Third, the survival data collected for the compacted cells suggest that there is a strong fertilizer effect from the straw and manure mulch since the survival of the black walnut seedlings fell to ≈ 0%. It is possible that the lack of grass and legume competition in the compacted cell that received no mulch treatment accounts for the nearly 34% survival of black walnut.

Growth in height for black walnut reflects the established trend with significant differences between the three subsurface treatments (Table 1). The height of this species in the loose-dump plots is best, strike-off is next, and compacted is last. Straw and manure mulch resulted in the best height growth for black walnut for the loose-dump plots, but for plots subjected to the strike-off technique, growth in height was the same for both the bark and straw/manure mulches (Fig. 5). On the compacted plots, growth in height was less on the hardwood bark plots than the other two surface treatments.

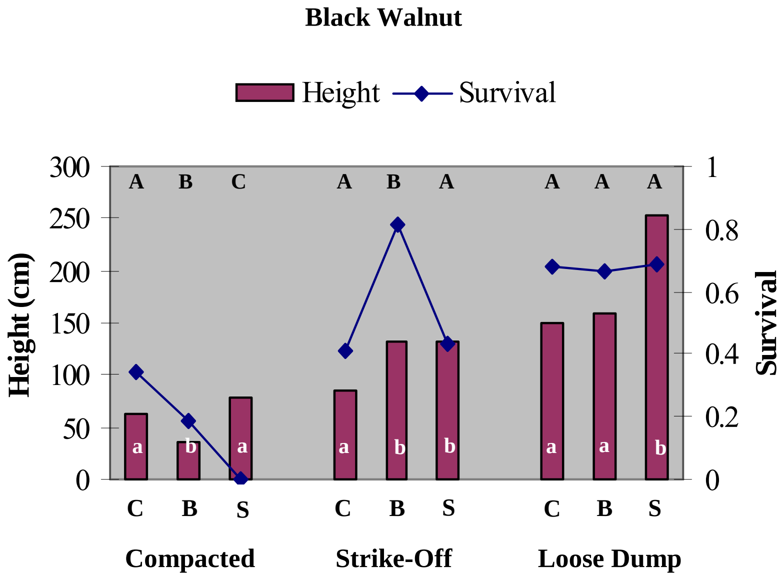

Figure 5. Mean cumulative height (cm) and survival rate for black walnut for the three surface treatments (C = control; B = bark mulch; S = straw/manure mulch) and the three subsurface treatments (Compacted; Strike-off; Loose-dump). Means with the same letter are not significantly different at the p = 0.05 confidence level. Capital letters refer to statistical relationships for survival, while lower case letters refer to height.

<u>Yellow Poplar</u>

As with white oak, white pine, and northern red oak, there is a general increase in the mean survival rate for yellow poplar as the compaction level was decreased. All three subsurface treatments are significantly different from each other (Table 1). Loose-dumped plots did significantly better than strike-off plots, and strike-off plots did significantly better than the compacted plots. The survival rate of yellow poplar was 10% in the compacted plots and 80% in the loose-dumped plots. In regards to the effect of the surface treatments on survival of yellow poplar, there is no significant difference in the three surface treatments on survival for the loose-dumped plots (Fig. 6). There is also no difference between the two mulches on the strike-off plots and a fertilizer effect of the straw and manure mulch may be present in the compacted plots as reflected by survival rates that are lower than those in the bark mulch and no mulch treatments.

Growth in height for yellow poplar reflects the established trend with significant differences between the three subsurface treatments (Table 1). The height of this species in the loose-dump plots is best, strike-off is next, and compacted is last. This trend exists for growth in height for the surface treatments in the strike-off plots but not for the other two plots (Fig. 6). There was a significant difference between straw/manure and the other two mulches for both the loose-dumped and compacted plots, with the straw/manure mulch resulting in the best height.

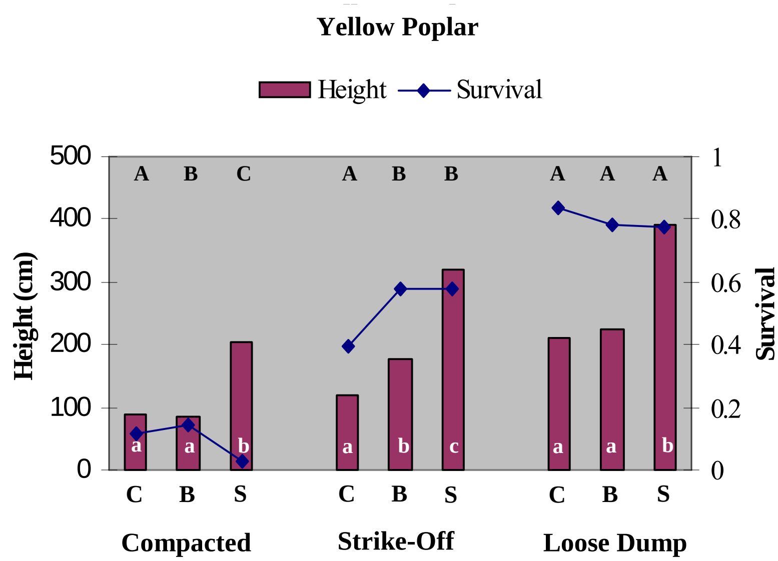

Figure 6. Mean cumulative height (cm) and survival rate for yellow poplar for the three surface treatments (C = control; B = bark mulch; S = straw/manure mulch) and the three subsurface treatments (Compacted; Strike-off; Loose-dump). Means with the same letter are not significantly different at the p = 0.05 confidence level. Capital letters refer to statistical relationships for survival, while lower case letters refer to height.

<u>Summary</u>

SMCRA requires regrading of the landscape after mining is complete to approximate original contour (AOC). In general, the reclamation practices used to achieve AOC produce a compacted rooting medium that is unsuitable for most forested species. Our research shows that reduced grading is critical for the survival and growth of planted seedlings.

All six tree species, with the exception of white ash, showed increased survivability as compaction was minimized. Additionally, the loose-graded techniques led to enhanced growth in height for the seedlings. The addition of surface amendments (mulches) also showed additional benefit but results varied by species and by treatment. Results definitively show that strike-off and loose-dump techniques improve seedling height and survival. The data also suggests that even a small amount of traffic (i.e. one or two passes per the strike-off method) may result in enough compaction to significantly reduce survival and growth in some species, such as yellow poplar and white pine.

For the establishment of forests on mined lands we recommend that in the backfilling and grading process, spoil material should be placed and compacted according to standard engineering practices so that the required stability and AOC is achieved. However, the top 1.2 to 1.8 m (4 to 6 ft) of material should not be graded or only lightly graded so that it is as uncompacted as possible.

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