TREE SURVIVAL ON A MOUNTAINTOP SURFACE MINE IN WEST VIRGINIA[1]

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Abstract: Due to increasing environmental pressure, the state of West Virginia has recently changed its regulations that govern reclamation of mountaintop surface mines. The state regulatory authority now requires the development of commercial forestry as the only agronomic post-mining land use acceptable for mountaintop surface mines that seek a variance from returning the land surface to approximate original contour (AOC). The Samples mountaintop surface mine in southern West Virginia has obtained AOC variances and therefore has commercial forestry as a post-mining land use. Operators of the Samples Mine have initiated a reforestation program where about 20,000 trees per year (roughly 20 ha per year) have been planted at the site over the past six years. During 2002, West Virginia University researchers established belt transects (4.8 m wide by 100 to 200 m in length) in 55 plantations at the site to determine survival of planted trees and to evaluate tree height and stem diameter. Evaluations were performed on plantations established in the spring of 1999 and the spring and fall of 2001. In each transect, slope, aspect, and ground cover were measured, and survival and growth of trees were analyzed according to these site conditions. Average tree survival across these three planting seasons and among all tree species was 65%. Black alder (*Alnus glutinosa* (L.) Gaertn.) was the largest of the planted trees, but sycamore (*Platanus occidentalis* L.), pine (*Pinus* spp.), white ash (*Fraxinus americana* L.), red maple (*Acer rubrum* L.), and black cherry (*Prunus serotina* Ehrh.) also showed good growth. Slope was used as a surrogate for soil compaction (steeper slopes tended to be reclaimed with smaller equipment compared to flatter slopes) and tree survival was 75% on slopes >50%, 62% on slopes 31-50%, and 67% on slopes <30%. Tree survival was not different among five aspect classes (ranging from 59% on W aspects to 68% on E aspects). Tree survival was significantly higher (74%) on areas with <50% ground cover and lower (62%) on areas with >70% ground cover.

Additional Key Words: aspect, compaction, ground cover, hardwoods, reclamation, reforestation, slope.

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Introduction

Coal mining is an important industry to the economy of West Virginia and has been for the past 100 years. In the heart of the Appalachian Highlands, the geology under West Virginia's boundaries is composed of 117 named coal seams, 65 of which are considered suitable for mining by underground and surface methods. Coal mining in West Virginia accounts for 15% of total coal production in the United States and 47% of U.S. coal exports (West Virginia Office of Miners Health, Safety, and Training, 2001). In 2001, 142 million Mg or metric tonnes (157 million U.S. tons) of coal were produced by underground and surface mines in WV (West Virginia Coal Association, 2002), which provided about 45,000 jobs and $12 billion in overall economic impact. About 351 surface mine permits produced more than 55 million Mg (61 million tons) of coal in 2001. All currently operating surface mines in WV total 117,000 ha (288,000 ac), with about 64% or about 75,000 ha (185,000 ac) currently disturbed (West Virginia Coal Association, 2002).

Recent changes in the Surface Mining and Reclamation Rule (38CSR2) that governs mining and reclamation activity in West Virginia have set new limits on post-mining land use options for permits that receive a variance from returning mined land to its approximate original contour (AOC). Permits with AOC variances that do not have an entity (such as an industry, store, or other organization that will build on the site) prepared to occupy the reclaimed mine site are now limited to commercial forestry as a post-mining land use. Though the new regulations eliminate the less productive, past land use options of rangeland and wildlife habitat, they also impose fairly strict performance standards on coal operators pursuing commercial forestry for the benefit of an AOC variance. To achieve full bond release, standards require high survival rates of planted, commercially valuable tree species and these trees must demonstrate suitable growth over a 12-year bonding period after final reclamation. Permits with commercial forestry as a post-mining land use that do not meet commercial tree species survival and productivity requirements after 12 years face a mitigation plan that may require an amount up to twice the remaining bond amount to be paid to the Special Reclamation Fund or require the coal operator to perform in-kind equivalent mitigation. Failure to achieve performance standards could be very costly for permit holders that operate mountaintop surface mines that generally seek AOC variances.

Revegetation of surface mines generally occurs concurrently with reclamation to ensure timely bond release. Erosion control and slope stability are important components of an effective reclamation and revegetation plan. Early establishment of tree seedlings in areas that require reforestation is important to ensure that performance standards both in terms of survival and growth are achieved within the time frame set by the new regulations.

The objective of this research was to assess several factors that influence tree survival and growth on mountaintop surface mines in West Virginia. Evaluating tree survival across many species and among various site and environmental planting conditions may allow coal operators to improve reclamation practices that will favor tree establishment and growth, thereby reducing the chance of failure on commercial forestry post-mining land uses.

Materials and Methods

Catenary Coal's Samples Mine in southern WV is the largest surface mine in the eastern U.S. with contiguous permits covering over 3,000 ha (7,400 ac). Mountaintop removal is the dominant surface mining method on this site and several areas have been permitted with commercial forestry as the post-mining land use.

The geology of the area being mined is within the Pennsylvanian System, and most disturbed strata is from the Pottsville, Kanawha, and Allegheny Formations. Seven major coal seams or coal zones (with 14 separate splits) are mined. In descending order, the coal seams are the Upper and Lower Freeport, Upper and Lower Kittanning, Stockton, Coalburg, and Winifrede.

A topsoil substitute has been allowed at the Samples Mine Complex in all permits prior to 2001 with or without an AOC variance, and also for areas permitted after 2001 without an AOC variance. The areas sampled during the summer of 2002 were reclaimed with a topsoil substitute that consists primarily of strata immediately above the deepest coal seam mined. This material placed at the surface consists of about 80% fine to medium grained, micaceous, light gray sandstone (unweathered) and 20% of a mix of shale and coal. The pH of the surface material (1:1 soil/water paste) ranged from 6.0 to 8.0. The recent changes to West Virginia mining regulations limit the use of topsoil substitutes to areas without AOC variances. Within AOC variance areas, the state now requires that 1.2 m (4 feet) of loose material must be spread over the reclaimed terrain. The material must consist of all the native soil material that can be salvaged from the area (A through C horizons) and as much weathered, slightly acid brown sandstone, from within 3 m (10 feet) of the surface, necessary to make up the required volume. This requirement reflects studies by Torbert et al. (1990) and Burger and Torbert (1992) that recommend weathered, acid, brown sandstone over alkaline siltstone as a major component of topsoil substitutes to be utilized on Appalachian surface mines with forestry as a post mining land use.

The management at Samples has established an aggressive reforestation program where more than 100,000 trees have been planted in small blocks of 0.2-10 ha during the past five or six years (~20,000 trees per year for a total of 20 ha per year). These plantations were the focus of this tree survival and growth study.

Tree plantations ranging from one to three years old of various sizes and various tree compositions were mapped and evaluated for seedling survival and growth during the summer of 2002. Belt transects (4.8 m wide) were run through plantations perpendicular to planted rows. Since plantations varied in size, we first mapped each plantation using a hand-held GPS unit and Autocad mapping software. Following the perimeter of each plantation, coordinates were recorded from a Garmin e-Trex Vista (Garmin International, Olathe, KS) and point data were later entered into the mapping program. We then attempted to evaluate about 1/10th of the total area of each plantation by running enough belt transects to represent 10% of the plantation area. Once we knew the size of the plantation, transect starting points were systematically located at the bottom (low elevation) of the plantation, perpendicular to the contour. Therefore, if the plantation was long along the contour and extended a short distance up the hill, more belt transects were needed since the belt transects in this plantation were relatively short. Alternatively, if the plantation was relatively narrow along the contour but extended a long distance up the hill, then transects were fewer and longer. Regardless of the geometry of the plantation, about 10% of the planted area was sampled by varying the number and length of transects.

Within transects, each tree was identified by species and its height and basal diameter were measured. In each transect, general site conditions were measured: slope was measured by a clinometer; aspect was determined by compass degree; and ground cover percentage and composition (total and by major species) were visually estimated. Calibration for visual ground cover estimation was achieved through practice with m^2 wire grids laid out in areas of variable cover, and we periodically reviewed field reference charts used for estimating percentages of cover for mottles and coarse fragments in soil profile description (Munsell Color Company, Inc., 2000).

Planting date, slope, aspect, and ground cover were separated into categories for analysis. Plantations for this tree survival study were planted in the spring of 1999 and the spring and fall of 2001. Slope was separated into three categories and used as a surrogate for compaction. This concept was taken from the work of Andrews et al. (1998), who found an inverse correlation between slope and bulk density in their study of 78 plantations on 14 different mines in southern West Virginia and Virginia. The three categories of slope: <30% (heavily compacted), 30-50% (moderately compacted), and >50% (lightly compacted), were decided upon through observations of tree growth and reclamation practices at the Samples mine.

Aspect was divided into the four cardinal directions (i.e., the North aspect included any aspect from NW to NE, the East aspect included NE to SE directions, etc.). Ground cover was separated into three categories: <50%, 50-70%, and >70% based on observations of greater tree growth in areas with less than 50% ground cover and the regulatory requirement of 70% ground cover prior to Phase I bond release. Statistical analyses were performed using analysis of variance (SAS Institute, 1987) using these factors as main effects on tree survival. Two-way interactions were also tested for their influence on tree survival, but are not shown here.

Results and Discussion

During 2002, 55 different tree plantations were mapped covering about 50 ha of land area. A total of 126 transects, covering approximately 4 ha of area or about 8% of the total plantation areas, were established to evaluate tree survival. Transects varied in size between and within the irregularly-shaped plantations (by the method stated above), with transects ranging from 0.003 ha (7 m long) to 0.067 ha (140 m long), averaging about 0.020 ha (42 m long). Based on planting records and observed planting patterns, the stocking density for each plantation was determined, and the densities for the plantations varied from 1,000 trees/ha to 5,434 trees/ha, with an average of about 1,482 trees/ha.

Tree plantations sampled in this study were established in the spring of 1999, spring of 2001, and fall of 2001. No significant difference in survival was found among the three planting dates, the older plantations had slightly less survival (58%) than 2001 plantations (66%, Table 1). Tree survival varied from 9% to 98% in plantations we sampled, averaging 65% across all ages of plantations. We were unable to evaluate the survival of each species because we didn't know exactly how many of any one particular species had been planted. However, we had relative proportions of individual species (Table 2), and our assessment was based on the total number of trees that had been planted in a specific plantation (based on the spacing pattern).

Table 1. Average survival of trees planted in Spring 1999, Spring 2001, and Fall 2001 at the Samples Mine.

Planting Date	Transect Area (ha)	# of Transects	Mean Survival (%)	Standard Deviation
Spring 1999	0.44	11	58	18.9
Spring 2001	1.26	60	68	20.8
Fall 2001	0.88	52	64	18.8

Table 2. Proportions of the planted trees based on planting records from the Samples Mine.

Species	Scientific Name	Proportion (%)
Black Alder	*Alnus glutinosa*	7
Sycamore	*Plantanus occidentalis*	6
Chestnut Oak	*Quercus prinus*	5
Bur Oak	*Quercus macrocarpa*	11
White Oak	*Quercus alba*	23
Sawtooth Oak	*Quercus accutissima*	4
Red Oak	*Quercus rubra*	1
White Ash	*Fraxinus americana*	35
Red Maple	*Acer rubrum*	1
Pitch x Loblolly Pine	*Pinus rigida x taeda*	2
White Pine	*Pinus strobes*	1
Dogwood	*Cornus florida*	3
Black Cherry	*Prunus serotina*	1

Black alder, a nitrogen fixing nurse tree, was the largest tree in all plantations and within each planting date. Other species showing good growth were sycamore, pitch x loblolly pine, white ash, red maple, and black cherry (Table 3). In comparing growth between Spring 2001 and Fall 2001, very little difference could be found. Table 4 provides a summary of values for survival, height, stem diameter, number of species, transect numbers and areas for each of the three planting dates.

Researchers have studied the negative influence of compaction on survival and growth of trees planted on surface mined land. Compaction, resulting from regrading the topsoil to make it smooth for planting, restricts root growth and retards the establishment and growth of trees (Larson and Vimmerstedt, 1983; Burger, 1999; Torbert et al., 2000).

Table 3. Average height and diameter of trees planted at three dates at the Samples Mine.

	Spring 1999			Spring 2001			Fall 2001		
Species	# Obs.	Ave Ht. (cm)	Ave Dia. (mm)	# Obs.	Ave Ht. (cm)	Ave Dia. (mm)	# Obs.	Ave Ht. (cm)	Ave Dia. (mm)
Black alder	40	167	29	172	95	18	6	124	24
Sycamore	21	102	19	133	45	7	44	45	6
Chestnut oak	2	23	4	129	45	8	29	46	6
Bur oak	44	61	12	298	38	8	9	33	7
White oak	107	39	6	413	38	6	255	42	7
Sawtooth oak	34	43	5	38	37	5	47	39	5
Red oak	9	29	5	5	41	6	0	-	-
White ash	175	80	12	694	50	8	306	46	6
Red maple	7	77	13	9	38	6	27	47	7
Pitch x Loblolly	21	82	19	3	25	6	32	23	5
White pine	6	64	17	0	-	-	0	-	-
Dogwood	19	36	5	39	36	5	53	38	5
Black cherry	13	63	7	10	50	5	0	-	-

Table 4. Average survival, height, diameter, and other parameters of all trees planted at three dates at the Samples Mine.

	Spring 1999	Spring 2001	Fall 2001
Ave Ht of all trees (cm)	71.3	47.3	44.3
Range of Ht of all trees (cm)	21-187	14.5-220.7	9-132.3
Ave Dia of all trees (mm)	12.47	7.7	6.1
Range of Dia of all trees (mm)	3-39.8	2.8-42.7	2-25.7
# of Species Encountered*	11	8	8
Ave # Species/Transect	7	5	5
Range of # of Species/Transect	4-11	1-8	1-8
# of Transects	14	60	52
Area of Transects (ha)	0.44	1.36	0.88
Ave Area of Transects (ha)	0.03	0.02	0.02
Range of Transect Area (ha)	0.01-0.05	0.003-0.67	0.007-0.04
# of Plantations Sampled	6	23	26

* Includes invaders.

Torbert and Burger (1996) found a significant difference in survival and height growth of commercially valuable trees planted to moderately and intensely graded spoils. Zeleznik and Skousen (1996) found that survival and average height growth of white ash, tulip poplar (*Liriodendron tulipfera* L.), and white pine were greater on sites subjected to low grading intensity.

Although no direct measurements of compaction were performed, the extremes of slope, <30% and >50%, were considered as analogs to conditions of compaction and a surrogate for soil bulk density. The reasoning behind the designation of the lower class representing a more compacted condition comes from observations at the site of the use of heavier equipment to regrade flatter slopes, and the use of lighter equipment to regrade steeper slopes, as well as less truck and equipment traffic associated with steeper slopes. Mean survival was highest in areas with steeper slope (Table 5), but the difference was not statistically significant.

Table 5. Average survival of trees planted from 1999 – 2001 on three slope classes at the Samples Mine.

Slope Class	Range	n	Mean Survival (%)	Standard Deviation
1	0 – 30%	52	67	19.1
2	31 – 50%	62	62	21.0
3	> 50%	9	75	11.5

Aspect has long been recognized as a factor that influences species composition and forest site quality in the eastern United States. South and west facing slopes are generally the least productive, while north and east facing slopes are the most productive (Hicks et al., 1982). Haynes (1983) found sparser plant communities on drier, south-facing aspects, while northern aspects had more vigorous plant communities, which was related to improved moisture conditions. Soil moisture and energy relationships in native forests have produced environments that favor the establishment and proliferation of certain species on certain aspects.

Studies of tree planting suggest that trees adapted to drier site conditions [pines (*Pinus spp*.), black locust *(Robinia pseudo-acacia* L.), and red oak] be established on southern and western aspects. Trees adapted to wetter and cooler climates [black walnut, black cherry, yellow-poplar, cottonwood (*Populus deltoides* Marsh.), green ash (*Fraxinus pennsylvanica* Marsh.), white ash, sweet gum (*Liquidambar styraciflua* L.)] should be planted on northern and eastern aspects.

The effects of aspect were considered in this study, but no significant differences in tree survival among aspects were found (Table 6). The Samples Mine Complex is predominantly a dragline operation. Removal of overburden and extraction of coal proceeds across the landscape as a series of trenches, or pits, with spoil piled to the limit of the dragline's reach. Reclamation results in series of rounded hill tops and ridges that run in line with the once open trenches. The effect of aspect on soil moisture at the Samples Mine may be muted by the fact that the difference in relief of the reclaimed terrain is generally less than 150 feet. Also, the oldest reclaimed terrain on which plantations were evaluated in this study was less than three years old and differences in soil development and energy cycling are not yet apparent. More time is probably needed for trees to be exposed to these various aspect conditions for survival differences to show.

Table 6. Average survival of trees planted during 1999-2001 on five aspect classes at the Samples Mine.

Aspect Class	Range (°)	Major Direction	n	Mean Survival (%)	Standard Deviation
1	316 - 45	NW-NE	13	66	25.6
2	46 - 135	NE-SE	33	68	17.8
3	136 - 225	SE-SW	15	65	17.2
4	226 - 315	SW-NW	31	59	22.0
5	< 30% slope	All	31	68	18.3

The negative effects of overly abundant and aggressive ground cover on the survival and growth of trees planted on reclaimed mine lands has long been known. Trees planted into introduced, aggressive forages [especially tall fescue (*Festuca arundinacea* L.) and sericea lespedeza (*Lespedeza cuneata* L.)] often are overtopped by the grass or legume and are unable to break free (Burger and Torbert, 1992; Torbert et al., 1995). The seedlings are pinned to the ground and have little chance for survival. If it is known that trees are to be planted, a tree-compatible ground cover should be seeded that will be less competitive with trees. Tree compatible ground cover should be slow growing, sprawling or low growing, not alleopathic, and non-competitive with trees (Burger and Torbert, 1992). Plass (1968) reported that after four growing seasons the height growth of sweetgum and sycamore planted into an established stand of tall fescue on spoil banks was significantly retarded. Andersen et al. (1989) found that survival and height growth for red oak and black walnut (*Juglans nigra* L.) was significantly greater on sites where ground cover was chemically controlled.

In this study, measured ground cover varied from 0% to 95% in transects, averaging 71%. Ground cover species included: annual and perennial rye, clovers, birdsfoot trefoil, alfalfa (*Medicago sativa* L.), bicolor and sericea lespedeza (*Lespedeza* spp.), orchardgrass (*Dactylis glomerata* L.), K-31 tall fescue, timothy (*Phleum pratense* L.), and redtop (*Agrostis alba* L.). Ground cover composition varied greatly between plantations, reflecting many different seed mixes that have been experimented with on this mine site. Tree survival was significantly higher ($p<0.05$) with <50% ground cover than with >70% ground cover (Table 7). The impact of ground cover on tree survival was noticeable in less than three years after planting.

Table 7. Average survival of trees planted during 1999-2001 with three ground cover classes at the Samples Mine.

Ground Cover Class	Range (%)	# of Transects	Mean Survival (%)	Standard Deviation
1	< 50	5	74	5.5
2	50 – 70	61	67	7.6
3	> 70	57	62	8.2

Summary

During the summer of 2002, we sampled 55 plantations using 126 transects at the Samples surface mine in West Virginia to determine the effects of planting date, slope, aspect, and ground cover on the survival of planted trees. Plantations were established in the spring of 1999 and the spring and fall of 2001. Average tree survival across these three dates and among all tree species was 65%. Black alder was the largest of the planted trees, but sycamore, pine, white ash, red maple, and black cherry also showed good growth. Slope was used as a surrogate for soil compaction and tree survival was 75% on slopes >50% (least compacted), 62% on slopes 31-50% (moderately compacted), and 67% on slopes <30% (heavily compacted). Tree survival was not different among five aspect classes (ranging from 59% on W aspects to 68% on E aspects). Tree survival was significantly higher (74%) in areas with <50% ground cover and lower (62%) in areas with >70% ground cover. More time is needed to see if these tree survival trends continue.

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