Hardwood Tree Survival in Heavy Ground Cover on Reclaimed Land in West Virginia: Mowing and Ripping Effects

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Current West Virginia coal mining regulations emphasize reforestation as a preferred postmining land use on surface mined areas. Some mined sites reclaimed to pasture are being converted to forests. In the spring of 2001, we compared the establishment and growth of five hardwood tree species on a reclaimed West Virginaia surface mine with compacted soils and a heavy grass groundcover. We planted 1-yr-old seedlings of five species (black cherry [*Prunus serotina* Ehrh.], red oak [*Quercus rubra* L.], yellow poplar [*Liriodendron tulipifera* L.], black walnut [*Juglans nigra* L.], and white ash [*Fraxinus americana* L.]) into sites that were mowed and unmowed on north- and south-facing aspects. We applied a ripping treatment, which loosened the compacted soils and disturbed the heavy ground cover. First year results showed >80% survival for all species. After 7 yr black cherry survival averaged 36%, red oak 47%, yellow poplar 66%, black walnut 80%, and white ash 98% across all sites and treatments. Seedling survival was best on north, unmowed, and ripped areas. Average growth (height × diameter^2) of trees after 7 yr was greatest with white ash (434 cm^3), followed by yellow poplar (256 cm^3) and black walnut (138 cm^3), then by black cherry (31 cm^3) and red oak (27 cm^3). Browsing by wildlife had a negative impact on tree growth especially on south aspect sites. Overall, mowing reduced survival of black cherry, red oak, and yellow poplar, but not for black walnut and white ash. Ripping increased survival of black cherry, red oak, and yellow poplar. Growth of all species was improved with ripping. Using inverse linear-quadratic plateau models, the time required for tree survival to stabilize varied from 1 yr for white ash to 6 to 9 yr for the other species.

About 78% of West Virginia is forested and, with the prevailing climate, almost all land in this region will naturally revert to forestland eventually if disturbed by fire, farming, or mining. The climate and soil/geology of the central Appalachians is conducive to some of the best hardwood forest growth in the world.

Surface coal mining disturbed about 2.5 million ha (6 million acres) since 1930 in the United States (Paone et al., 1978; Plass, 2000). In Appalachia, the vast majority of surface mined land was originally covered by eastern deciduous forest. The earliest laws governing reclamation of surface mines were passed in Ohio, Pennsylvania, and West Virginia during the 1940s, and these laws required mine operators to register with the state and pay bonds to ensure reclamation after mining. Early reclamation laws prescribed soil, subsoil, and overburden (the geologic material overlying the coal) to be used to refill the excavated area. Backfilling and leveling the land was specified, and conifers and some hardwood tree species were planted to replace the forest which had been removed (Ashby, 2006; Brown, 1962; Limstrom, 1960; Plass, 2000). Reforestation was chosen because the land had been originally forested and reforested sites provided long-term site stabilization, wildlife habitat, and future economic value when trees are harvested (Torbert and Burger, 2000).

Since the late 1970s with the passage of a national surface mining law, most surface mined land in Appalachia has been reclaimed to pasture and hay land or wildlife habitat postmining land uses (Plass, 1982; 2000) rather than forestland. The reasons for this land use change related to: (i) quick economic returns to landowners by grazing and haying systems, (ii) predictable bond release because the consistent ground cover gave good erosion control and water quality, and (iii) better land stability compared to prelaw mined landforms where no grading was performed (Boyce, 1999). Tens of thousands of hectares have been reclaimed to pasture in Appalachia during the 1970s to 2000. Reclamation to pasture or hay land achieves the objectives of surface mining reclamation laws and is economically viable when the site is maintained with fertilizer, lime, and forage removal. But problems develop if these agronomic practices are neglected because the plant community of high-maintenance forages can quickly collapse and revert to a barren, eroded landscape of weedy and undesirable species. Trees

Published in J. Environ. Qual. 38:1400–1409 (2009).
doi:10.2134/jeq2008.0297
Received 27 June 2008.
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Abbreviations: ARRI, Appalachian Regional Reforestation Initiative; BS, base saturation; CEC, cation exchange capacity; EC, electrical conductivity; FBC, fluidized bed combustion ash.

will return eventually, but a long time must pass as the site succeeds through a series of unproductive plant communities until valuable hardwood species ultimately invade back onto the site and the canopy closes (Gorman et al., 2001; Potter et al., 1951; Zeleznik and Skousen, 1996).

There are several factors important to restoring a productive forest on mined lands that makes reforestation more complex than establishing hay land or pasture. Survival and growth of trees is often weather dependent and less predictable compared to the establishment and growth of forage species. Replanting of trees is expensive and reclamation success relies on tree survival and in some cases height growth of the trees. Losing a year or two of tree growth because of poor weather or browsing by animals can delay the release of money held in reclamation bonds.

Another important factor to establishing a productive forest on mined areas is related to the physical and chemical properties of the replaced topsoil (Ashby, 1997; Rolf, 1994; Torbert and Burger, 1990). Several studies have shown rapid physical weathering of blasted rock materials ("substitute" topsoil) when placed on the surface for revegetation and the fast development of soil horizons (Haering et al., 1993, 2004; Roberts et al., 1988; Sencindiver and Ammons, 2000). Substitute topsoil composed of weathered "brown" sandstone can be found at the top of the geologic profile and has been chemically weathered over millennia. Substitute topsoil can also be made from unweathered "gray" material, which is located at lower depths in the geologic profile, and these gray materials tend to develop slower than weathered materials. The unweathered materials have an alkaline pH, variable sized particles, adequate supplies of nutrients, and enough water for grass and tree growth (Burger and Torbert, 1992). Recent regulations for commercial forestry postmining land uses in West Virginia require replacement of native topsoil and weathered brown sandstone material to a depth of 1.2 to 1.5 m rather than unweathered gray materials (Emerson and Skousen, 2007). Substitute materials made from weathered brown sandstone immediately underlying the soil profile are usually lower in pH and are composed of fine materials and weathered rock fragments, which appear to be more conducive to hardwood tree growth (Emerson and Skousen, 2008; Skousen et al., 2006), rather than unweathered gray materials with high pH that favor forages.

Pasture and hay land postmining land uses require the surface to be regraded and the topsoil to be spread smoothly across the surface so farm equipment can remove forage. Due to the prominent selection of this postmining land use and the corresponding laws and regulations, operators and regulators have been conditioned to expect smooth, compacted, lawn-like reclamation with a consistent cover of grasses and legumes. However, for reforestation, uncompacted, loose soil material, regardless of its weathered or unweathered condition, has been shown to be a preferred rooting media for trees (Ashby, 2006; McFee et al., 1981). Reclamation cost savings can also be realized by operators when reclaiming to forestland because less grading is required (Burger and Torbert, 1992). These non-compacted surfaces also tend to have less erosion because water infiltrates into the loose soil rather than running off of compacted soil (Sweigard et al., 2007b).

Poor survival and growth of hardwood species has occurred especially when tree seedlings are planted into heavy herbaceous ground cover (Burger and Torbert, 1990; Holl, 2002; Torbert and Burger, 2000). Trees planted into introduced aggressive forages (especially tall fescue [*Festuca arundinacea* L.] and sericea lespedeza [*Lespedeza cuneata* L.]) are often overtopped by the grasses or legumes, and are unable to break free through the coverage (Burger and Torbert, 1992; Torbert et al., 1995). The seedlings are pinned to the ground and have little chance for survival.

Another major factor to tree establishment comes from rodent and deer (and other wildlife species) damage and this damage is often closely related to the amount and type of ground cover (Brown, 1962; Deitschman, 1950; Limstrom and Merz, 1949). Part of this problem may be reduced by planting a tree-compatible ground cover, which does not produce as thick of a ground cover needed by voles (*Microtus* spp.) and other rodents, and which has fewer and smaller seeds available for rodent food. The tree compatible ground cover should be slow growing, sprawling or low growing, not allelopathic, and not present competition to trees (Burger and Torbert, 1992). In our region, whitetail deer (*Odocoileus virginianus*) damage is often extensive. Deer will simply walk down the rows of planted tree seedlings and browse the leaves and tops, and sometimes break off the stems by rubbing their antlers.

Reforestation of mined land has gradually emerged during the early 2000s as a preferred postmining land use option due to results from long-term research programs (Ashby and Kolar, 1977; Burger and Torbert, 1992; Torbert and Burger, 2000; Zeleznik and Skousen, 1996). A recent technology transfer effort to deal with the obstacles of forest re-establishment based on these research programs is the Appalachian Regional Reforestation Initiative (ARRI) created by the USDI Office of Surface Mining. The ARRI encourages a five-step process to reclaim coal mined land to forestland called the Forestry Reclamation Approach:

1. Create a suitable rooting medium for good tree growth that is no less than 1.2 m (4 ft) deep and comprised of topsoil, weathered sandstone, and/or the best available material;
2. Loosely grade the topsoil or topsoil substitutes established in step one to create a noncompacted growth medium;
3. Use ground covers that are compatible with growing trees;
4. Plant two types of trees– (i) early succession species for wildlife and soil stability, and (ii) commercially valuable crop trees;
5. Use proper tree planting techniques (Burger et al., 2005).

This initiative targets active mining and ongoing reclamation and has only recently (2005) been systematically applied to coal operators. Because so much area has been reclaimed to pasture with compacted soils and heavy ground cover in Appalachia, converting such areas to a commercially valuable forest has become a priority (Sweigard et al., 2007a; Ussiri et al., 2006). Ripping has been successful in loosening compacted minesoils for tree growth (Ashby, 1996; 1997; Kost et al., 1998) and herbicides have been used to reduce the ground cover competition (Ashby, 1997; Casselman et al., 2006; Chaney et al., 1995; Torbert et al., 2000). Mowing has been used to reduce ground cover height but it can lead to a thicker and more competitive ground cover in ensuing years (Haywood et al., 1993).

The objectives of this research were to (i) test pasture-to-forest conversion techniques that might mitigate the effects of grassland reclamation and provide conditions for successful reforestation and (ii) evaluate survival and growth responses of selected native hardwood species to site amelioration treatments. A surface mining company was required to establish a hardwood forest on a recently reclaimed surface mine near Morgantown, WV. The site had been reclaimed to a pasture postmining land use where the topsoil was only 30 cm thick and compacted, and where aggressive forage species were seeded, all of which have been shown to reduce survival and growth of trees that may be planted on the site. Before planting trees into this compacted and heavy ground-covered area (and knowing that the tree planting would probably fail based on previous experience), the company contracted researchers at West Virginia University to evaluate methods to modify the soil and site conditions to improve the chance for hardwood tree survival and growth. Therefore, we selected five hardwood species (black cherry, red oak, black walnut, yellow poplar, and white ash) and planted them at four sites on the reclaimed area. Mowed and unmowed areas on both north and south-facing aspects were developed. A ripping treatment was applied into the design at each site to reduce soil compaction and to disturb the heavy ground cover. Survival and growth of the hardwood trees were determined during the ensuing 7 yr.

Materials and Methods

A 1-yr-old reclaimed area located 10 km west of Morgantown, WV (39°39′30′′ N, 80°03′00′′ W) was selected for this reforestation study. The area had been surface mined for the Waynesburg seam of coal (Pennsylvanian System, Monongahela Group) during 1997 to 2000, and the overburden was composed of 75% sandstone and 25% shale and mudstone. After backfilling and regrading to approximate original contour, a 15-cm layer of fluidized bed combustion ash (FBC) was applied to the surface. This ash was supplied by the Morgantown Energy Associates FBC power plant, and the ash had a pH of 11, and a calcium oxide content of about 20%. The ash was placed on the backfill as a liming agent, and the ash also was used to retard the movement of water downward into the backfill because of the cementing properties of the ash on wetting. Application of FBC ash is a standard practice on Waynesburg surface mines in this area because it solves the problem of ash disposal and it prevents acid mine drainage formation due to the alkalinity of the ash and its sealing capacity. After FBC ash placement, bulldozers respread and compacted 25 to 30 cm of topsoil which had been removed and stored before mining. The area was fertilized with 275 kg ha^{-1} of 10–20–10 fertilizer, and seeded with 33 kg ha^{-1} tall fescue, 18 kg ha^{-1} orchardgrass (*Dactylis glomerata* L.), 18 kg ha^{-1} birdsfoot trefoil *(Lotus corniculata* L.), and 40 kg ha^{-1} annual winter wheat (*Triticum aestivum* L.). The grasses and legumes formed a consistently thick ground cover. It should again be noted that Steps 1 through 3 of the ARRI Forestry Reclamation Approach (Burger et al., 2005) were not followed at this site for reforestation, but instead the land was reclaimed to a pasture using only 30 cm of topsoil, heavy soil compaction, high fertilization, high seeding rates, and aggressive forage species.

Four sites of about 0.25 ha each were established on the reclaimed area. Elevation of the sites was about 372 m (1220 feet) above sea level and slopes were about 15%. Sites 1 and 2 were located on a north-facing aspect, while Sites 3 and 4 were directly adjacent on a south-facing aspect.

Sites 1 and 3 were mowed, while no mowing was done at Sites 2 and 4. Mowing was performed every month from May through September for the first year (2001) in an attempt to reduce ground cover competition from the aggressive herbaceous species and to minimize cover for rodents. Mowing to reduce ground cover for tree growth is not used frequently because ground cover control is more often accomplished with herbicides. However, we chose mowing because circumstances prevented the use of herbicides at this site. Mowing was done with a walk-behind, rotary brush hog mower between tree rows, and ground cover was mowed when it reached 20 to 30 cm and cut to a height of 5 cm. Mowing was performed only for the first year of the experiment (2001). We observed that mowing produced denser grass/legume growth which may have increased ground cover competition and that it also exposed trees to increased deer and rodent predation as reported by McGowan and Bookhout (1986).

At each site, four plots were established. Each plot was 400 m^2 (20 by 20 m) in size, with one-half of each plot being ripped and other half not ripped. The ripping treatment consisted of a single-blade ripper attached to a bulldozer that ripped the minesoil to a depth of 1 m along the contour. This treatment was designed to reduce minesoil compaction and to break up the potential hardened layer of ash beneath the topsoil, and it also disturbed the consistently thick ground cover.

Within each plot, 60 seedlings were planted: 30 hardwood seedlings (six seedlings of each species: black cherry, red oak, black walnut, yellow poplar, and white ash) were planted in ripped areas and 30 in unripped areas. The seedlings were planted alternatively at 1-m spacing with mattocks to provide a mixed hardwood stand. A total of 240 seedlings were planted at each site (five species × six replications × two ripping treatments × four replicated plots), and 960 seedlings were planted on all four sites (192 seedlings per species). Site preparation and planting occurred in April 2001.

Survival was determined for all planted trees 6 mo after planting (first year-September 2001), after two growing seasons (second year-September 2002), after five growing seasons (fifth year-August 2005), and after seven growing seasons (seventh year-August 2007). Height and diameter (2 cm above ground level) were determined for each live tree during the fifth and seventh years. Tree growth was calculated by multiplying height × $diameter^2$ (Casselman et al., 2006).

Soil samples were collected at five randomly selected points on Sites 1 and 2, (north-aspect) and five samples were taken from Sites 3 and 4 (south-aspect) in 2001 and 2007 at two depths: 0 to

15 cm (topsoil) and 35 to 40 cm (subsoil–ash layer). Soil analyses included pH (1:1 soil:water, McLean, 1982), electrical conductivity (EC) (Rhoades, 1982), texture (Gee and Bauder, 1986), and percent coarse fragments (>2 mm by weight). Extractable Ca, K, Mg, and Na were determined by 1 mol L^{-1} NH_4OAc extraction (Sumner and Miller, 1996) and extractable acidity by 1 mol L^{-1} KCl (Soil Survey Staff, 1996). Cation exchange capacity (CEC) was calculated by summing extractable bases by NH_4OAc and extractable acidity by KCl, while base saturation (BS) was calculated by total base cations divided by CEC.

Statistical analyses were performed using SAS 9.1 software (SAS Institute, 2005). Using Proc GLM means statement, Fisher's *t* tests were applied to test for differences in mean survival for each species across years, and for differences in ripping treatments within sites for each species. The *t* tests were also used to evaluate site differences for survival of each species. An α level of 0.05 was considered significant. Data normality was assessed using histograms and no normalization was necessary. An inverse linear-quadratic plateau model (Proc NLIN, SAS 9.1) was used to determine trends for tree survival and to estimate the time at which survival became constant for each species at each site.

Results and Discussion

Soil Properties

Before the experiment was established, we dug holes to 50 cm in the soil to observe the conditions. The 0 to 15 cm soil depth had a clay loam texture with an average of 13% coarse fragments >2 mm in size (data not shown). The material at 25 to 40 cm depth had a sandy loam texture. It was evident that the FBC ash layer had formed a continuous weakly cemented layer. This cementation of the FBC ash layer would justify classifying this as a restrictive zone for plant rooting and water uptake, which confirmed the need for a ripping treatment. Subsequent digging after ripping showed that the ash layer was broken up into coarse fragments and we measured about 50% coarse fragments in the subsoil in ripped areas. The tree roots might not have been significantly influenced by the cemented ash layer 30 cm below the surface during the early stages of tree growth, but root restrictions will probably occur as root growth continues, which may translate into reduced survival and growth of trees over time. We also expect that the fragments of cemented ash will degrade into silt-sized particles over time.

Topsoil of Sites 1 and 2 (north aspect) were significantly lower in pH (pH 5.0–5.6) at 0 to 15 cm depth than those of Sites 3 and 4 (south aspect) with a pH of 7.2 in 2001 and 2007 (Table 1). In 2001, subsoil pH was >8.0 and was similar at all four sites, but subsoil pH declined significantly by 2007. In 2007, subsoil pH was significantly different between Sites 1 and 2 and Sites 3 and 4. The more acid topsoil on Sites 1 and 2 caused the initial high pH of these subsoils (pH 8.3) to decrease to pH 4.8 after 7 yr. But we also observed a decline in pH of subsoils at Sites 3 and 4 (pH 6.4) where no acid topsoil was present, so clearly the alkalinity in the ash layer was decreased by leaching and weathering over time regardless of the topsoil pH. This leaching is substantiated by a decrease in soluble salts (EC), K, Ca, Mg, and BS in the subsoils over time (Table 1).

We initially were concerned about the high subsoil EC values on tree survival and growth since some agronomic crops are affected by EC values of 2 dS m^{-1} or more (Jurinak et al., 1987), but reductions in yield are generally only noticeable with EC values of 4 dS m^{-1} or greater, especially in humid regions (Sobek et al., 2000). Most hardwood trees are adapted to moderately acid conditions and EC values <2 dS m^{-1} (Rodrigue and Burger, 2004). Based on the differences in soil chemistry and aspect among the four sites, Sites 1 and 2 would be expected to be more conducive to hardwood tree survival and growth because of the slightly acid pH in the topsoil and also to the generally improved moisture conditions of north-facing aspects. Since such large differences were found in topsoil pH among sites, the aspect factor has been compromised. Therefore, we will refer to Sites 1 and 2 as those that have north aspect-low soil pH properties vs. Sites 3 and 4 with south aspect-high soil pH properties.

Tree Species Survival

First-year survival of black cherry across all sites was high (82%), but it declined to an average of 36% after the seventh year (Table 2). Survival dropped quickly on most sites, but less so on ripped areas. On Sites 1, 3, and 4, we found a significantly higher survival in ripped areas (denoted by ‡ in Table 2), which is probably due to tree roots having a channel of loosened soil in which to grow and the channels also capturing water and directing it to the roots. Site 4 (south aspect-high soil pH and mowed) appeared to have the poorest survival for black cherry. Black cherry is capable of survival across a broad spectrum of soils and landforms. It is generally considered to be a pioneer species with a weak taproot and a shallow spreading rooting habit, therefore ripping should have improved survival for this species. We observed that mowing during the first year of the study appeared to increase the competitiveness of the ground cover and made the tree seedlings more visible to deer. Mowing was originally included in the design because we did not want the grasses to overtop the trees and smother them or pin them to the ground, plus we were unable to use herbicides on this property. But, because of the observed deer browsing especially on mowed sites, we discontinued mowing for the duration of the study for fear of complete tree mortality in mowed areas. In both mowed and unmowed sites, every one of the black cherry seedlings was browsed by deer, and the damage from girdling and browsing eventually resulted in >60% tree mortality. Survival was only 36% by the end of the study period.

Using the survival data, the time required for each species to reach a constant survival value was estimated with an inverse linear-quadratic plateau model (SAS Institute, 2005). As an example of this analysis, Fig. 1 shows black cherry survival over time at Site 1 in ripped areas and the graph denotes the time when the trend line reached a plateau, which is reported as the "time required" to reach a stable tree population in Table 2. The length of time required for black cherry to reach a constant survival value was estimated to be 5 to 8 yr (Table 2). This length of time is important because regulations require a specified number of trees to be alive to achieve bond release, and depending on the postmining land use the evaluation for bond release could occur 5 yr after planting or 12 yr after planting.

Table 1. Comparison of soil properties of topsoil and subsoil (subsoil and FBC ash layer) on Sites 1 and 2 (north-facing aspect) and Sites 3 and 4 (south-facing aspects) of our reclaimed surface mine in northern West Virginia in 2001 and 2007.

Horizon	pH	EC†	CEC	Acid	BS	K	Ca	Mg
		dS m^{-1}	cmol$_c$ kg^{-1}		%	cmol$_c$ kg^{-1}		
2001								
Sites 1 and 2 topsoil	5.0 ± 0.3‡	0.2 ± 0.04	14 ± 1.2	7.2 ± 0.4	48 ± 4	0.2 ± 0.01	5.2 ± 0.04	1.3 ± 0.3
Sites 1 and 2 subsoil	8.3 ± 0.5	2.3 ± 0.07	48 ± 5.5	0	100 ± 0	0.1 ± 0.03	45 ± 5.6	2.4 ± 0.5
Sites 3 and 4 topsoil	7.2 ± 0.3	0.2 ± 0.04	26 ± 3.2	0	100 ± 0	0.2 ± 0.02	23 ± 3.4	3.7 ± 1.4
Sites 3 and 4 subsoil	8.7 ± 0.6	2.5 ± 0.05	47 ± 6.2	0	100 ± 0	0.3 ± 0.04	45 ± 4.8	1.9 ± 0.8
2007								
Sites 1 and 2 topsoil	5.6 ± 0.2	0.1 ± 0.02	13 ± 2.1	3.8 ± 0.13	71 ± 7	0.2 ± 0.01	7.7 ± 0.78	1.5 ± 0.4
Sites 1 and 2 subsoil	4.8 ± 0.5	1.2 ± 0.09	14 ± 1.9	8.4 ± 2.40	40 ± 5	0.2 ± 0.02	4.4 ± 0.64	1.1 ± 0.4
Sites 3 and 4 topsoil	7.2 ± 0.4	0.1 ± 0.05	19 ± 2.3	0	100 ± 0	0.2 ± 0.01	16 ± 3.8	2.7 ± 1.1
Sites 3 and 4 subsoil	6.4 ± 0.5	1.5 ± 0.05	16 ± 3.2	1.8 ± 0.07	89 ± 12	0.1 ± 0.02	11 ± 1.5	2.8 ± 0.6

† EC, electrical conductivity; CEC, cation exchange capacity; BS, base saturation.

‡ Means ± standard deviations are given.

Table 2. Average survival of planted black cherry seedlings for on four sites with ripping treatments on a surface mine in West Virginia after first (2001), second (2002), fifth (2005), and seventh (2007) growing seasons. The time required to reach a constant survival value based on inverse linear-quadratic plateau models is also given.

	Black cherry seedlings				
Treatments	First	Second	Fifth	Seventh	Time required
	%				yr
Site 1 (N,UM)†					
Unripped‡	50 a§	17 b	17 b	13 b	5
Ripped	92 a	54 b	37 b	37 b	5
Site 2 (N,M)					
Unripped	92 a	54 b	42 b	33 b	6
Ripped	87 a	58 b	46 b	42 b	6
Site 3 (S, UM)					
Unripped‡	79 a	67 ab	54 b	54 b	6
Ripped	100 a	87 ab	75 b	75 b	6
Site 4 (S,M)					
Unripped‡	67 a	50 a	12 b	8 b	7
Ripped	92 a	83 a	29 b	25 b	8
Average	82	58	39	36	

† N = North, S = South, UM = Unmowed, M = Mowed.

‡ Unripped and ripped treatments for that site were significantly different at the 0.05 level.

§ Values across years for a specific site and ripping treatment with different letters are significantly different at the 0.05 level.

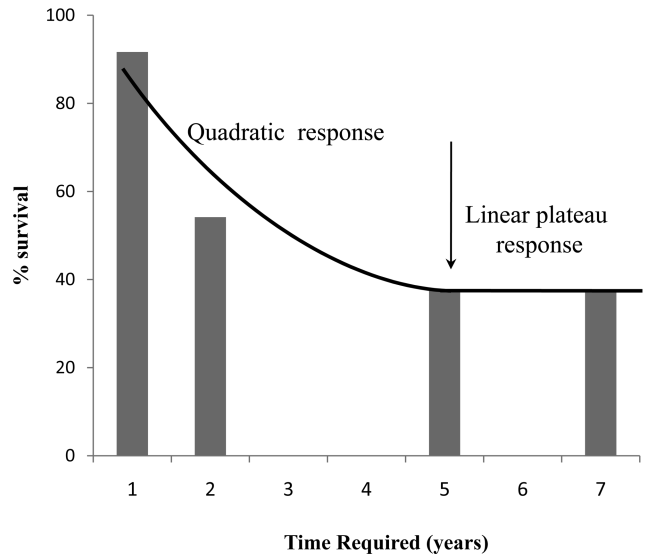

Fig. 1. Black cherry survival over 7 yr on Site 1 (north-low soil pH and unmowed) in ripped areas. The trend line estimates the time when survival was a quadratic function and when survival became a linear plateau function. The time required for black cherry to reach a constant survival value on this site was 5 yr as shown by the arrow.

Survival of red oak was 96% after the first year, which declined to 47% survival after the seventh year (Table 3). Red oak survival was significantly greater in ripped areas only at Site 4 (south-high soil pH and mowed), even though there was a trend for higher survival in ripped areas at the other sites. One might expect that Sites 1 and 2 with a north aspect and lower soil pH would show greater survival since red oak prefers north and northeastern aspects and low pH soils (Hicks, 1998), but this was not the case since survival at Site 3 (south-high soil pH and unmowed) was the same as Sites 1 and 2. Red oak is generally considered to be a climax species that grows slowly as a juvenile. It favors root growth over top growth early on, and its taproot allows it to survive moisture stress. Perhaps its inherently slow root growth made ripping less important for survival. However, only 12% red oak survival was found on the unripped areas at Site 4 (south-high soil pH and mowed). The time required for red oak survival values to stabilize was estimated between 6 and 9 yr, while the unripped area on Site 2 required 17 yr (Table 3).

Yellow poplar survival averaged 92% after the first year across all sites, but that number declined to 66% after the seventh season (Table 4). Not surprisingly, survival was the highest at Site 1 (north-low soil pH). Site 1 did not show a significant ripping effect, while all the other sites did. Yellow poplar is an exploitive species that can move onto disturbed areas and take advantage of unused nutrients and water. It has a fast-growing taproot with many lateral roots, and usually requires 3 yr to establish. The unripped areas at Site 4 (south-high soil pH and mowed) had only 8% yellow poplar survival, which was similar to black cherry and red oak on the same site and treatment. The drier south aspect with higher pH soils, the mowed treatment with increased ground cover competition and browsing, and the unripped areas where no channels were available for water capture and root extension had a combined detrimental effect on survival of these tree seedlings. Survival was good overall at Site 1 (north-low soil pH and unmowed) and on ripped areas of Site 2 (north-low soil pH and mowed) and Site 3 (south-high soil pH and unmowed). The time required to reach stable tree survival values varied from 1 to 8 yr (Table 4).

Black walnut showed high survival rates of >90% during the first 2 yr after transplanting (Table 5). By the seventh year, walnut survival still averaged 80%. Black walnut is generally found on well-drained soils and prefers higher soil pH. It has good early growth because it supports a large taproot with strong lateral roots. Ripped areas showed contradicting results at Sites 2 and 3. Ripped areas at Site 2 (north-low soil pH and mowed) had significantly higher survival than the corresponding unripped area, while unripped areas at Site 3 (south-high soil pH and unmowed) had significantly higher black walnut survival than ripped areas. Black walnut average survival was the highest at Site 4 (south-high soil pH and mowed), which is the exact opposite of black cherry, red oak, and yellow poplar. Our high black walnut survival rates agree with similar results from other studies with this species on surface mined land (Andersen et al., 1989; Ashby and Kolar, 1977). Black walnut survival stabilized between 1 and 15 yr on these sites (Table 5). Site 4 (south-high soil pH) in both the unripped and ripped areas showed good survival of black walnut over time.

In discussing the favorable black walnut survival results with other foresters in the region, they mentioned that survival of this tree after planting into minesoils is quite unpredictable and our long-term survival results were surprising (J. Burger, Virginia Tech, personal communication, 2008). These foresters also explained that long-term productivity of black walnut is much more questionable than other tree species such as yellow poplar and red oak. Some foresters have witnessed a decrease in black walnut performance when planted in minesoils due to insufficient availability of moisture and nutrients for this site-demanding species. Black walnut is not planted frequently on mined lands because of the large root system of 1-yr-old planting stock and the effort needed to open a sufficiently large hole for the root system. Therefore, despite our findings and those of other scientists, high numbers and widespread planting of black walnut has not been done in this region and should be approached with caution based on the unpredictable results of past performance trials.

White ash had the best survival of the five species. All trees survived after the first and second years (Table 6), and only one tree (on a ripped area at Site 1) out of the original 192 died during the third year. A few more trees died at Sites 2 and 4 by the seventh year. White ash has shown good survival on other sites (Zeleznik and Skousen, 1996) and often survives better than any other planted tree species (Ashby, 2006). White ash can grow on a wide range of soils and tends to show good height growth. This tree has a taproot but it has strong branching lateral roots. The time required to reach a stable population for this species was generally only 1 yr. White ash was the most noticeable of the trees on our site because of its height, but it also was browsed heavily. Sadly, foresters predict an almost complete demise of white ash during the next two decades due to the emerald ash borer (*Agrilus planipennis* Fairmaire.).

Table 3. Average survival of planted red oak seedlings for on four sites with ripping treatments on a surface mine in West Virginia after first (2001), second (2002), fifth (2005), and seventh (2007) growing seasons. The time required to reach a constant survival value based on inverse linear-quadratic plateau models is also given.

	Red oak seedlings				
Treatments	First	Second	Fifth	Seventh	Time required
	%				yr
Site 1 (N,UM)†					
Unripped	100 a‡	79 ab	58 bc	50 c	7
Ripped	95 a	94 a	62 b	62 b	9
Site 2 (N,M)					
Unripped	100 a	83 b	62 c	46 d	17
Ripped	100 a	83 b	65 c	56 c	6
Site 3 (S,UM)					
Unripped	96 a	75 a	50 b	50 b	6
Ripped	100 a	91 a	58 b	54 b	7
Site 4 (S,M)					
Unripped§	87 a	46 b	12 c	12 c	6
Ripped	100 a	79 b	42 c	37 c	6
Average	96	79	52	47	

† N = North, S = South, UM = Unmowed, M = Mowed.

‡ Values across years for a specific site and ripping treatment with different letters are significantly different at the 0.05 level.

§ Unripped and ripped treatments for that site were significantly different at the 0.05 level.

Table 4. Average survival of yellow poplar planted seedlings on four sites with ripping treatments on a surface mine in West Virginia after first (2001), second (2002), fifth (2005), and seventh (2007) growing seasons. The time required to reach a constant survival value based on inverse linear-quadratic plateau models is also given.

	Yellow poplar seedlings				
Treatments	First	Second	Fifth	Seventh	Time required
	%				yr
Site 1 (N,UM)†					
Unripped	100 a‡	100 a	100 a	100 a	1
Ripped	100 a	96 a	87 a	87 a	6
Site 2 (N,M)					
Unripped§	96 a	79 ab	58 bc	50 c	8
Ripped	100 a	96 a	96 a	92 a	1
Site 3 (S,UM)					
Unripped§	75 a	71 a	62 a	62 a	6
Ripped	100 a	100 a	92 ab	87 b	7
Site 4 (S,M)					
Unripped§	71 a	21 b	8 c	8 c	5
Ripped	83 a	50 b	27 c	25 c	6
Average	92	80	69	66	

† N = North, S = South, UM = Unmowed, M = Mowed.

‡ Values across years for a specific site and ripping treatment with different letters are significantly different at the 0.05 level.

§ Unripped and ripped treatments for that site were significantly different at the 0.05 level.

Final survival values across sites and treatments after the seventh year are shown in Table 7 and *t* tests were used to denote significant differences. Black cherry and white ash did not show a significant aspect–soil pH effect (Sites 1 and 2 vs. Sites 3 and 4). Black walnut had significantly higher survival on Sites 3 and 4 (south-high soil pH) compared to Sites 1 and 2 (north-facing low soil pH), while the reverse was true for red oak and

Table 5. Average survival of planted black walnut seedlings on four sites with ripping treatments on a surface mine in West Virginia after first (2001), second (2002), fifth (2005), and seventh (2007) growing seasons. The time required to reach a constant survival value based on inverse linear-quadratic plateau models is also given.

	Black walnut seedlings				
Treatments	First	Second	Fifth	Seventh	Time required
	%				yr
Site 1 (N,UM)†					
Unripped	100 a‡	79 ab	58 bc	50 c	9
Ripped	95 a	94 a	62 b	62 b	6
Site 2 (N,M)					
Unripped§	96 a	92 a	71 b	58 b	15
Ripped	100 a	96 a	87 a	87 a	3
Site 3 (S,UM)					
Unripped‡	96 a	96 a	96 a	87 a	5
Ripped	91 a	71 b	67 b	62 b	8
Site 4 (S,M)					
Unripped	91 a	87 a	87 a	79 b	2
Ripped	100 a	92 a	92 a	92 a	1
Average	95	90	84	80	

† N = North, S = South, UM = Unmowed, M = Mowed.

‡ Values across years for a specific site and ripping treatment with different letters are significantly different at the 0.05 level.

§ Unripped and ripped treatments for that site were significantly different at the 0.05 level.

Table 6. Average survival of planted white ash seedlings on four sites with ripping treatments on a surface mine in West Virginia after first (2001), second (2002), fifth (2005), and seventh (2007) growing seasons. The time required to reach a constant survival value based on inverse linear-quadratic plateau models is also given.

	White ash seedlings				
Treatments	First	Second	Fifth	Seventh	Time required
	%				yr
Site 1 (N,UM)†					
Unripped	100 a‡	100 a	100 a	100 a	1
Ripped	100 a	100 a	100 a	100 a	1
Site 2 (N,M)					
Unripped	100 a	100 a	100 a	96 a	3
Ripped	100 a	100 a	100 a	100 a	1
Site 3 (S,UM)					
Unripped	100 a	100 a	100 a	100 a	1
Ripped	100 a	100 a	100 a	100 a	1
Site 4 (S,M)					
Unripped	100 a	100 a	100 a	96 a	3
Ripped	100 a	100 a	92 a	92 a	5
Average	100	100	99	98	

† N = North, S = South, UM = Unmowed, M = Mowed.

‡ Values across years for a specific site and ripping treatment with different letters are significantly different at the 0.05 level.

yellow poplar. Black walnut tends to prefer higher soil pH so this result is not surprising. After the seventh year, mowing significantly reduced survival for black cherry, red oak, and yellow poplar, but showed no effect on black walnut and white ash. Even with mowing every month only during the first year, this treatment caused a significant reduction in survival after 7 yr for three tree species. The increased cover competition coupled with browsing resulted in greater tree mortality with mowing.

Table 7. Average survival after 7 yr for each species on four sites with ripping treatments on a surface mine in West Virginia. The *t* tests were used to determine significant differences for main effects.

Treatments	Black cherry	Red oak	Yellow poplar	Black walnut	White ash
	%				
Aspect– soil pH					
Sites 1 and 2 (N)†	31	56‡	82‡	74‡	99
Sites 3 and 4 (S)	40	39	50	85	97
Mowing					
Sites 1 and 3 (UM)	45‡	54‡	84‡	80	100
Sites 2and 4 (M)	27	41	48	79	96
Ripping					
Unripped	27‡	40‡	55‡	76	98
Ripped	45	55	77	83	98
Average	36	47	66	80	98

† N = North-5.5 soil pH, S = South-7.2 soil pH, UM = Unmowed, M = Mowed.

‡ Seedling survival for that species was significantly different for that main effect (aspect, mowing, or ripping).

And as already noted, ripping was found to significantly increase survival for black cherry, red oak, and yellow poplar.

Growth

A combination of height and diameter (height × diameter ^{2}) was used to evaluate growth over time because of the extensive damage on all the trees by deer. The browsing resulted in reducing tree height by consuming tree tops and leaves, or by actually breaking stems by rubbing or trampling. The trees responded by sprouting more stems from the base. Negative impacts of deer and rodent predation and browsing on planted trees were found in other studies (Brown, 1962; Deitschman, 1950; Limstrom and Merz, 1949). While all the trees received damage, which often would have been reflected as a reduction in height over time, the diameter of these browsed trees generally increased, which when multiplied with a shorter height often resulted in a positive growth value. Table 8 shows the average values of growth at the end of the seventh year for each species within sites and ripping treatments. The percent change between 2005 and 2007 is shown as a positive or negative number because the average growth value of that species at that site could have either decreased in growth due to browsing or increased in growth due to height and diameter development. On average, growth of white ash, not surprisingly, was highest of these five trees at 434 cm^3, followed by yellow polar at 256 cm^3 and black walnut at 138 cm^3, then by black cherry (31 cm^3) and red oak (27 cm^3). The percent change in growth values between 2005 and 2007 generally followed the same pattern with white ash at +124% and red oak at +35%. However even with a low average growth value in 2007, black cherry actually showed an average percent change of more than +100% due primarily to the growth on Sites 1 and 2 (north-low soil pH). In almost all cases for all five species, growth was greatest on ripped areas of Site 2 (north-low soil pH and mowed), while the poorest growth was on unripped areas of Site 4 (south-high soil pH and mowed). The high growth on Site 2 is somewhat surprising since this was a mowed site, and we already showed that survival on mowed sites was lower than unmowed sites. Black cherry, black walnut, and white ash had their

Table 8. Growth (cm³)† at the end of 7 yr and percent change‡ in growth between the fifth and seventh years on four sites with ripping treatments on a surface mine in West Virginia.

Treatments	Black cherry		Red oak		Yellow poplar		Black walnut		White ash	
	cm^3	%	cm^3	%	cm^3	%	cm^3	%	cm^3	%
Site 1 (N,UM)§										
Unripped	12	+680	17	+69	312	+123	115	+63	308	+70
Ripped	29	+97	43	+35	1325	+579	275	+150	688	+189
Site 2 (N,M)										
Unripped	66	+392	44	+55	444	+168	301	+210	628	+159
Ripped	123	+189	45	+69	715	+202	513	+285	1278	+352
Site 3 (S,UM)										
Unripped	13	+10	11	−9	37	+37	51	−10	206	+112
Ripped	21	−5	35	+1	106	+15	148	+68	239	−6
Site 4 (S,M)										
Unripped	3	−77	16	+150	6	−56	30	−30	184	+104
Ripped	11	+35	17	+29	24	−31	55	+41	260	+27
Average	31	+111	27	+35	256	+112	138	+89	434	+124

† Growth (cm^3) is height × diameter².

‡ Percent change is the positive or negative percent change in growth between 2005 and 2007 height and diameter measurements.

§ N = North, S = South, UM = Unmowed, M = Mowed.

highest growth on Site 2 in both the ripped and unripped areas and it is unclear why growth was higher on Site 2 than on Site 1. We expected that tree survival and growth would be greatest on Sites 1 and 2 (north-low soil pH) and probably in unmowed sites (Site 1), which it was for survival. The unmowed areas reduced the visibility of the trees to deer and may not have increased the competitive nature of the ground cover like mowing did. Nevertheless, Site 2 had the greatest growth across all species.

Both unripped and ripped areas at Sites 1 and 2 (north-low soil pH) showed positive growth (between +35 and +680) for all tree species. At Sites 3 and 4 (south-high soil pH), negative growth was found in unripped areas for black cherry, red oak, yellow poplar, and black walnut, and in ripped areas for black cherry, yellow poplar, and white ash. Sites 3 and 4 (south–high soil pH) were found to be less favorable habitats for tree growth (even for black walnut). We expect that incremental height growth will increase at a greater rate during the next several years now that roots have had 7 yr to become established and now that many of the trees are obtaining heights that put them out of deer browsing reach. We expect this rate of increase to be greatest on Sites 1 and 2, but we also expect to observe greater growth increases in ripped areas because roots have already or will soon confront the ash layer in unripped areas which will probably hinder growth and root expansion.

Summary and Conclusions

This study was conducted to evaluate ripping and mowing as remedial measures to convert a reclaimed pasture site (with thin compacted soils and heavy ground cover) to a forest of commercially valuable trees. After 7 yr, black cherry had 36% survival, red oak 47%, yellow poplar 66%, black walnut 80%, and white ash 98% across all sites and treatments. Survival was greater for red oak and yellow poplar at Sites 1 and 2, which were located on north aspects and had soil pH around 5.5, but black cherry, black walnut, and white ash survived as well on Sites 3 and 4 (south aspect with soil pH at 7.2) as they did on Sites 1 and 2. Unmowed sites showed significantly greater survival for black cherry, red oak, and yellow poplar, but not for black walnut and white ash. Ripping increased survival of black cherry, red oak, and yellow poplar, but not for black walnut and white ash. In general, Site 1 (north-low soil pH and unmowed) gave greater tree survival than Site 4 (south-high soil pH and mowed). Northern aspect sites (Sites 1 and 2) probably had improved soil moisture conditions and provided cooler temperatures than southern aspects, but these sites also had a lower soil pH (around 5.5) compared to Sites 3 and 4 (south aspect) with pH at 7.2. Soil pH of 5.5 is closer to the pH of native forest soils in the area. Higher survival on ripped areas was probably due to improved conditions for plant rooting and more available moisture caused by increased infiltration and collection of water in the ripped channels. In general, mowing resulted in lower tree survival due to presumably creating a denser vegetation cover, which may have competed with the trees for moisture and nutrients. Mowing also made the seedlings more susceptible to herbivores. Using inverse linear-quadratic plateau models, 5 to 9 yr was needed for trees to reach stable survival values on Sites 2 and 4 (unmowed) and 6 to 8 yr was needed on Sites 1 and 3 (unmowed).

Average growth (height × diameter²) of trees was greatest with white ash (434 cm^3), followed by yellow poplar (256 cm^3) and black walnut (138 cm^3), then by black cherry (31 cm^3) and red oak (27 cm^3). Deer browsing negatively influenced all the trees, but we saw actual reductions in growth on Sites 3 and 4 (south-high soil pH) between 2005 and 2007 due to deer browsing. Tree growth was greatest on Site 2 (north-low soil pH and mowed) and lowest on Site 4 (south-high soil pH and mowed). The combination treatment of Site 4 and unripped areas gave the lowest survival and growth values for black cherry, red oak, and yellow poplar.

This study shows that soil compaction and competition from a heavy ground cover of grasses and legumes negatively affect survival and growth of important native hardwood tree species. The Forestry Reclamation Approach is recommended when preparing mined sites for reforestation, which includes selecting suitable topsoil substitutes, dumping the material loosely to avoid compaction, and seeding a tree-compatible ground cover for erosion control. However, our study shows that remedial ripping of compacted minesoils improves survival and growth of most species regardless of site type. Many mined areas originally prepared for pasture and hay land postmining land uses (alkaline material, compacted soils, and competitive heavy ground cover) and not used for pasture could be more quickly converted to native forest and made more productive than that which will occur with natural succession.

Acknowledgments

The authors extend appreciation to Mr. Ron Hamric of Anker Energy Corporation (now International Coal Group) for initially funding this study. Special thanks are given to Dr. Jim Burger, Virginia Tech, and Dr. Robert Darmody, University of Illinois, for helpful suggestions and comments on the manuscript.

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