# FOURTH-YEAR TREE RESPONSE TO THREE LEVELS OF SILVICULTURAL INPUT ON MINED LANDS[1]

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**Abstract.** There is a surging interest in restoring forests on surface mined lands in the Appalachians. Many lands reclaimed since the passage of the Surface Mining Control and Reclamation Act of 1977 (SMCRA) have dense ground covers and compacted soil materials, in some cases associated with unfavorable soil chemical properties. To address these concerns, three previously reclaimed mined sites were located in Lawrence County, OH; Nicholas County, WV; and Wise County, VA. At each site, Eastern white pine, hybrid poplar, and mixed Appalachian hardwoods were planted at three levels of silvicultural intensity (weed control only, weed control with soil ripping, and weed control with soil ripping and fertilization). Each combination of species and treatment was repeated three times in each of the three states for a total of 9 replications and 81 treatment plots. The OH sites were dominated by compacted siltstone backfill with a thin topsoil cap, the WV sites by shale fragments through the profile and the VA sites by mixed shale and sandstone fragments through the profile with a crushed sandstone cap. Trees were measured in October of 2007 after 4 years of growth. Across all treatments and species, Virginia had a higher survival rate, 70.7%, than West Virginia, 49.4%, and Ohio, 40.3%. West Virginia had a higher biomass index per tree, 5,673 $cm^3$ (cubic centimeters), than Ohio, 1,446 $cm^3$ Across all states and treatments, the survival rates of mixed hardwoods, 63.2%, and hybrid poplar, 55.1%, were greater than that of Eastern white pine, 42.1%. Total biomass index per tree for hybrid poplar, 10,024 $cm^3$, was greater than that for Eastern white pine, 258 $cm^3$, and mixed hardwoods, 138 $cm^3$. Survival across all states and species was increased from 44% to 64% with ripping. Ripping plus weed control increased average biomass index from approximately 1,000 $cm^3$ per tree to 5,000 $cm^3$ per tree over weed control only. All species achieved their highest biomass values for this study on the West Virginia shale-based spoils and their highest survival rates on the Virginia sandstone-dominated spoils. When restoring forest vegetation to previously reclaimed mine sites with unfavorable soil and vegetation properties, the use of silvicultural treatments (weed control and soil ripping, with or without fertilization) can aid survival and growth.

Additional Key Words: compaction, ground cover, fertility, reforestation, native hardwoods, white pine, hybrid poplar, reclamation

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## Introduction

Across Appalachia, hundreds of thousands of hectares have been mined for coal under the Surface Mining Control and Reclamation Act. Many of these areas have been left in an unproductive state. Effective reforestation of these lands can produce many benefits. These include economic and aesthetic benefits to the landowner, environmental benefits such as restoration of pre-mining vegetative cover and habitat, watershed protection, sequestration of atmospheric carbon and production of woody biomass for industrial use. However, restoration of forest vegetation on these sites requires financial expenditure. Landowners or agencies choosing to reforest post-SMCRA mine sites face choices regarding the level of silvicultural inputs to be applied in reestablishing the native forest, and thus the level of establishment cost to be borne. Understanding the significant effect and cost differences between available silvicultural treatments is therefore important for realizing economically and biologically sound reforestation. Three common site limitations for trees on reclaimed mine sites are herbaceous competition, soil compaction and low levels of essential nutrients. There are also many options of tree species to use for reforestation based on reclamation goals and post-mining use objectives. This study examined both silvicultural and species factors.

The objective of this study was to evaluate the effects of silvicultural treatments on the survival and early growth of several tree species with potential for use in the reforestation of reclaimed surface mine lands in the Appalachians.

## Methods and Materials

### Background

The three silvicultural treatments studied were herbaceous weed control using herbicide, subsoil ripping, and fertilization. Experimental plots using three species groups were established in Ohio, Virginia and West Virginia. Species groups included Eastern white pine (*Pinus strobus*), hybrid poplar (*Poplus spp.*) and a mix of native Appalachian hardwoods. The experiment was begun with site preparation and planting in March of 2004. This paper is an analysis of measurements taken in October of 2007 following the fourth growing season. Greater detail on the establishment of the experiment and first-year survival and growth results can be found in Casselman *et al.* (2006) and Casselman (2005).

### Site Description

The Ohio (OH) sites were located at 38.75°N; 82.63°W in Lawrence County, the West Virginia (WV) sites at 38.13°N; 80.65°W in Nicholas County, and the Virginia (VA) sites at 37.05°N; 82.70°W in Wise County. These sites had been previously mined for coal before being reclaimed to grass. Grasses and legumes formed a dense vegetative cover at the time of tree establishment. Siltstone dominated the mine spoils on the sites in Ohio, shale dominated the West Virginia sites and sandstone dominated the Virginia sites; together these rock types are representative of the range of overburdens removed and then returned as spoils and soil substitutes on mined areas that are reclaimed in the Appalachian region (Casselman *et al.*, 2006).

There were other notable differences in reclamation techniques, vegetation and soil properties between the three sites. The Ohio siltstone minesoils had topsoil returned to cap the study areas to a depth of 5 to 51 cm. This was the sites' pre-mining topsoil that had been stored for post-mining replacement. The topsoil was more acidic, had lower electrical conductivity and lower bulk density than the underlying mine spoils. Having been reclaimed approximately 10 years previously, the Ohio sites were well vegetated with tall fescue (*Festuca arundinacea*) and sericea lepedeza (*Lespedeza cuneata*). Topsoil "capping," as occurred on the experimental sites, is a common reclamation practice in Ohio. The West Virginia shale mine soils had no topsoil cap and, upon reclamation approximately 10 years previously, had been revegetated with tall fescue that had been actively used for grazing. The mine soil had a high coarse fragment content and a high bulk density. The Virginia sandstone mine soils were capped with a soil substitute of crushed sandstone (Daniels and Amos, 1984) to a depth of 0 to 47 cm across the study area. Two Virginia study blocks had been reclaimed less than 5 years previously and vegetated with tall fescue and sweet clover (*Melilotus alba*), while the third had been reclaimed the previous year and revegetated with annuals. The Virginia soils had a high bulk density and high proportion of coarse fragments (Casselman *et al.* 2006).

<u>Species Description</u>

Eastern white pine has been commonly planted as a crop tree on southern Appalachian reclaimed surface mine lands (Torbert and Burger, 2000). Hybrid polar was also planted as an experimental treatment ( *Populus trichocarpa* L. (Torr. and Gray ex Hook.) x *Populus deltoids* (Bartr. Ex Marsh.) hybrid 52-225). The third species group included a mix of native

Appalachian hardwoods meant to simulate the forest composition that existed before mining (Table 1).

Table 1. Species combinations selected for Mixed Appalachian Hardwoods treatment in three states.

| **Species** | **Ohio** | **West Virginia** | **Virginia** |
|---|---|---|---|
| Bitternut hickory (*Carya cordiformis*) | 9.6% | 0.0% | 10.9% |
| Black oak (*Quercus velutina*) | 9.6% | 0.0% | 0.0% |
| Chestnut oak (*Quercus prinus*) | 19.2% | 0.0% | 0.0% |
| Flowering dogwood (*Cornus florida*) | 7.7% | 7.8% | 7.8% |
| Northern red oak (*Quercus rubra*) | 9.6% | 15.3% | 10.9% |
| Red maple (*Acer rubrum*) | 0.0% | 15.3% | 0.0% |
| Redbud (*Cercis canadensis*) | 7.7% | 7.8% | 7.8% |
| Scarlet oak (*Quercus coccinea*) | 9.6% | 0.0% | 0.0% |
| Sugar maple (*Acer saccharum*) | 9.6% | 15.3% | 10.9% |
| Tulip poplar (*Liriodendron tulipifera)* | 9.6% | 15.3% | 10.9% |
| Washington hawthorn (*Cretaegus phaenopyrum*) | 7.7% | 7.8% | 7.8% |
| White ash (*Fraxinus americana*) | 0.0% | 15.3% | 10.9% |
| White oak (*Quercus alba*) | 0.0% | 0.0% | 21.9% |

Trees were planted in these proportions on their respective sites in March of 2004. Eastern white pine was planted as 2-0 bare root seedlings, hardwood were planted as 1-0 bare root seedlings and the planted hybrid poplars were approximately 20 cm-long stem cuttings. Planting density for all species and treatments was 2.4m x 3.0m or 1,345 trees per hectare (Casselman *et al.*, 2006).

Silvicultural Treatments

*Weed Control*. All of the study areas received 9.35 liters per hectare of glyphosate broadcast across the study areas in August of 2003. In addition, 4.92 liters per hectare of a pre-emergent herbicide with pendimethalin for grass control was applied in April of 2004 after tree planting. Glyphosate was then used in spot applications immediately around each tree seedling in July of 2004 with the exception of one study block in Virginia where no competing vegetation was present. During the application process, seedlings were shielded from drifting herbicide (Casselman *et al.*, 2006).

*Subsoil Ripping.* Two-thirds of the study areas were ripped in the spring of 2004 prior to tree planting. Differing local availability caused a variety of equipment to be used including multiple shanks, single shank with bed-creating coulters, and single shank only. Ripping depths were set at 61 to 91 cm (Casselman *et al.*, 2006).

*Fertilization.* One-third of the study areas, which had also been ripped, were fertilized beginning in May of 2004 after seedling planting. Diammonium phosphate was applied in a banded pattern at a rate of 272 kg per hectare, adding 49.0 kg per hectare N and 55.1 kg per hectare P. Around the base of each seedling, 91 kg per hectare of muriate of potash and 20 kg per hectare of a micronutrient mix was applied adding 46.8 kg per hectare K, 1.8 kg per hectare S, 0.2 kg per hectare B, 0.2 kg per hectare Cu, 0.8 kg per hectare Mn and 4.0 kg per hectare Zn (Casselman *et al.*, 2006).

Tree Measurement and Data Analysis

Each treatment plot was 0.25 ha with a 0.04 ha 50-tree measurement plot nested inside. Survival was determined by dividing the number of surviving trees by the number of trees originally planted in each plot. This analysis looked at cumulative survival since the beginning of the experiment and not survival since the previous year.

Ground line diameter, diameter at breast height, and tree height were measured. Biomass index was calculated by: BI ($cm^3$) = $D^2$ ($cm^2$) x Ht (cm). The biomass indices of individual trees were summed to determine a plot biomass which was then divided by the number of surviving trees to determine an average biomass per tree. Therefore, the primary data analysis looked at the average biomass per surviving tree and is independent of survival rates.

Data were analyzed using JMP 7.0 (SAS Institute Inc., Cary NC). Differences in survival and growth among treatments within states were determined using a randomized block ANOVA. Tukey-Kramer HSD was used for mean separations ($P<0.05$). Multi-factor analysis was also performed to analyze species by treatment interaction and state effects.

## Results:

Tree Response to Treatments

Tree survival and growth were affected by silvicultural treatment, species selection and state location across the entire study and there were also interaction effects on growth (Table 2). Survival and growth of trees in Ohio were affected by species selection. Growth of trees in Virginia was affected by species selection. Survival and growth of trees in West Virginia were affected by silvicultural treatment and species selection and an interaction of species and treatment.

Survival

Survival was affected in some cases by the silvicultural treatments. Eastern white pine, mixed hardwoods and hybrid poplar survived equally well under all silvicultural treatments in Virginia (Table 3). This was also true of Eastern white pine in West Virginia and Ohio and of mixed hardwoods in Ohio. Mixed hardwoods and hybrid poplar in West Virginia survived better with tillage. Fertilization decreased survival of hybrid poplars in Ohio. Silvicultural treatment had no effect on overall survival in Virginia and Ohio but the addition of tillage did increase survival in West Virginia. Across all states and silvicultural treatments, mixed hardwoods and hybrid poplar had greater survival than Eastern white pine. Across all species and silvicultural treatments, Virginia had the highest overall survival rate. Across all species and states, the addition of tillage increased survival rates but the further addition of fertilization did not (Figure 1).

Table 2.

Analysis of variance results for survival and growth of trees planted on reclaimed mine sites.

| **Site and Source** | **Degrees of Freedom** | **Variable (Pr > F)** | |
|---|---|---|---|
| | | **Survival** | **Biomass Index** |
| **All Sites** | | | |
| Species | 2 | 0.0007 | <.0001 |
| State | 2 | <.0001 | 0.0017 |
| Treatment | 2 | 0.0016 | 0.0012 |
| Species x State | 4 | 0.0551 | 0.0002 |
| Species x Treatment | 4 | 0.3236 | <.0001 |
| State x Treatment | 4 | 0.0560 | 0.0643 |
| Species x State x Treatment | 8 | 0.6478 | 0.0409 |
| Model | 26 | | |
| Error | 54 | | |
| Total | 80 | <.0001 | <.0001 |
| **Virginia** | | | |
| Species | 2 | 0.1180 | <.0001 |
| Treatment | 2 | 0.1665 | 0.2302 |
| Species x Treatment | 4 | 0.6276 | 0.2204 |
| Model | 8 | | |
| Error | 18 | | |
| Total | 26 | 0.2508 | <.0001 |
| **West Virginia** | | | |
| Species | 2 | 0.0075 | <.0001 |
| Treatment | 2 | 0.0001 | 0.0169 |
| Species x Treatment | 4 | 0.2348 | 0.0075 |
| Model | 8 | | |
| Error | 18 | | |
| Total | 26 | 0.0007 | <.0001 |
| **Ohio** | | | |
| Species | 2 | 0.0131 | 0.0030 |
| Treatment | 2 | 0.2701 | 0.2470 |
| Species x Treatment | 4 | 0.5020 | 0.2209 |
| Model | 8 | | |
| Error | 18 | | |
| Total | 26 | 0.0812 | 0.0189 |

Table 3
Mean percent survival of all replications by species, state and treatment four years after establishment.

| Site and Treatment | Tree Species | | | | | | Treatment Mean | |
|---|---|---|---|---|---|---|---|---|
| | EWP | | MH | | HP | | | |
| Virginia | | | | | | | | |
| WC | 49.7 | a | 52.3 | a | 78.7 | a | **60.2** | **a** |
| WC+T | 77.0 | a | 82.3 | a | 82.0 | a | **80.4** | **a** |
| WC+T+F | 51.3 | a | 79.0 | a | 84.3 | a | **71.5** | **a** |
| Species Mean | **59.3** | **Z** | **71.2** | **Z** | **81.7** | **Z** | **70.7** | **A** |
| West Virginia | | | | | | | | |
| WC | 31.3 | a | 36.0 | b | 22.0 | b | **29.8** | **b** |
| WC+T | 60.7 | a | 73.7 | a | 62.3 | a | **65.6** | **a** |
| WC+T+F | 42.7 | a | 79.3 | a | 38.0 | ab | **53.3** | **a** |
| Species Mean | **44.9** | **Y** | **63.0** | **Z** | **40.8** | **Y** | **49.6** | **B** |
| Ohio | | | | | | | | |
| WC | 33.3 | a | 48.7 | a | 48.0 | ab | **43.3** | **a** |
| WC+T | 16.7 | a | 69.3 | a | 55.0 | a | **47.0** | **a** |
| WC+T+F | 18.3 | a | 48.3 | a | 25.7 | b | **30.8** | **a** |
| Species Mean | **22.8** | **Y** | **55.4** | **Z** | **42.9** | **ZY** | **40.4** | **B** |
| **All Sites Species Mean** | **42.3** | **Y** | **63.2** | **Z** | **55.1** | **Z** | **53.6** | |

*The same letter connecting treatment response data for each species means no significant difference at p = .05. Lowercase a's and b's: statistically same treatment means within state vertically. Uppercase A's and B's: statistically same state means across all treatments and species vertically. Uppercase Z's and Y's: statistically same species means across all treatments horizontally.

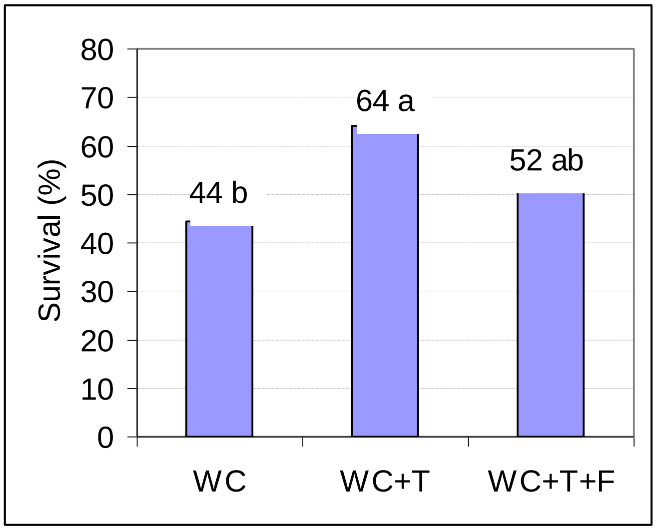


Figure 1. Survival for each treatment across all species and all states. Bars sharing the same letter are not significantly different.

Growth

Growth was also affected by the three experimental variables. Eastern white pine, mixed hardwoods and hybrid poplar grew equally well, within their species groups, under all silvicultural treatments in Virginia and Ohio (Table 4). This was also true of Eastern white pine and mixed hardwoods in West Virginia. Hybrid poplar in West Virginia grew faster with tillage but did not grow any faster than weed control only when fertilization and tillage were applied. Across all species, silvicultural treatment had no effect on growth in Virginia, West Virginia or Ohio. Across all states and silvicultural treatments, hybrid poplar grew faster than both Eastern white pine and mixed hardwoods. Across all species and silvicultural treatments, West Virginia had a higher growth rate than Ohio, but Virginia was not different from the other two states. Across species and states, the addition of tillage increased growth measured as biomass index but the further addition of fertilization did not (Figure 2).

Table 4
Mean biomass index [(groundline diameter)$^2$ x height] in cm$^3$
of all replications by species, state and treatment after four years.

| Site and Treatment | Tree Species | | | | | | Treatment Mean | |
|---|---|---|---|---|---|---|---|---|
| | EWP | | MH | | HP | | | |
| Virginia | | | | | | | | |
| WC | 261.5 | a | 333.9 | a | 5163.9 | a | **1919.8** | **a** |
| WC+T | 411.8 | a | 184.5 | a | 11806.9 | a | **4134.4** | **a** |
| WC+T+F | 304.5 | a | 321.6 | a | 10914.2 | a | **3846.8** | **a** |
| Species Mean | **325.9** | **Y** | **280.0** | **Y** | **9295.0** | **Z** | **3300.3** | **AB** |
| West Virginia | | | | | | | | |
| WC | 233.1 | a | 31.4 | a | 1577.8 | b | **614.1** | **a** |
| WC+T | 604.5 | a | 150.4 | a | 27159.6 | a | **9304.8** | **a** |
| WC+T+F | 358.4 | a | 101.5 | a | 20837.7 | ab | **7099.2** | **a** |
| Species Mean | **398.7** | **Y** | **94.4** | **Y** | **16525.0** | **Z** | **5672.7** | **A** |
| Ohio | | | | | | | | |
| WC | 101.5 | a | 33.9 | a | 1090.0 | a | **408.5** | **a** |
| WC+T | 29.5 | a | 58.7 | a | 4201.3 | a | **1429.8** | **a** |
| WC+T+F | 14.0 | a | 21.6 | a | 7466.8 | a | **2500.8** | **a** |
| Species Mean | **48.3** | **Y** | **38.1** | **Y** | **4252.7** | **Z** | **1446.4** | **B** |
| **All Sites Species Means** | **257.6** | **Y** | **137.5** | **Y** | **10024.2** | **Z** | **3473.1** | |

*The same letter connecting treatment response data for each species means no significant difference at p = .05. Lowercase a's and b's: statistically same treatment means within state vertically. Uppercase A's and B's: statistically same state means across all treatments and species vertically. Uppercase Z's and Y's: statistically same species means across all treatments horizontally.

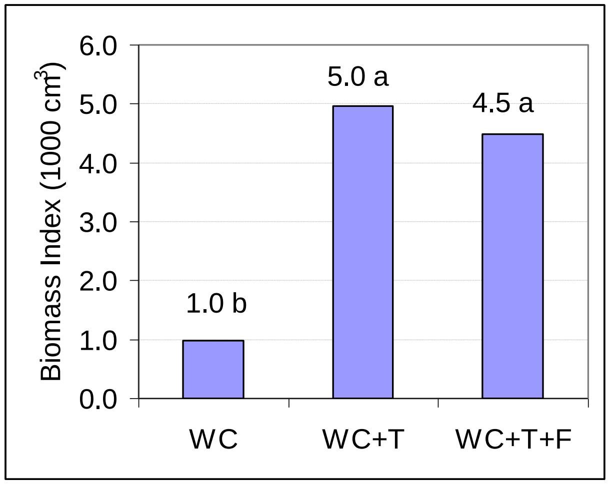


Figure 2. Biomass index per tree values for each treatment across all species and all states. Bars sharing the same letter are not significantly different.

## Discussion

Hybrid poplar had superior volume growth in all three states during the four-year period. Hybrid poplar had 72 times more biomass than the mixed Appalachian hardwoods and 39 times more than Eastern white pine across all sites. This hybrid poplar species is in a class by itself in terms of early growth potential. It is especially useful for sequestering carbon or producing woody biomass at least for short-term planning horizons.

West Virginia, with its shale-based, uncapped minesoils, produced nearly 4 times the growth of Ohio, with its siltstone minesoils capped with topsoil. The Virginia sandstones, capped with crushed sandstone soil substitute, had an intermediate value not significantly different from the other sites. One problem with comparing the three sites was the presence of confounding variables that affected the three sites differently, such as deer browse activity and the possibility that the previously grazed site in West Virginia had been fertilized while being actively grazed. Virginia had significantly greater survival rates across all treatments and species than West Virginia and Ohio. This suggests that the site factors that affect survival may differ from those that affect growth.

The addition of ripping to herbaceous weed control as a silvicultural treatment produced consistently beneficial results. Adding ripping increased survival significantly in West Virginia for mixed hardwoods and hybrid poplar.  It also increased growth significantly in West Virginia hybrid poplar.  For the overall study across all sites and species, ripping significantly improved both survival and growth.

Adding fertilizer along with weed control and ripping failed to produce any additional improvement in survival or growth in any aspect of this experiment.  In fact, it produced results that were statistically similar to the weed control treatment for hybrid poplar survival and growth in West Virginia and for overall survival rates across the entire experiment.  Applying powdered fertilizer to the base of young seedlings can cause severe damage and even mortality; the fertilizer treatment was applied in this way  by parties who were not aware of this problem during the experiment's establishment.  It is possible that fertilization could cause significant improvements in survival or growth if applied appropriately, but that cannot be inferred from this particular experiment.

Hybrid poplar and mixed hardwoods had significantly greater survival rates than Eastern white pine across all states and treatments.  This suggests that parties seeking to achieve high stocking rates when reforesting older mine sites might utilize hybrid poplar if biomass production is desired or native mixes of Appalachian hardwoods if native forest restoration is desired.

Another experimental result was that the variation between blocks that were designed as replications was often as great, or greater than, the variation between the species x state x treatment combinations that are being compared.  This could be due to micro-site factors related to the specific origin and geologic makeup of mine spoils deposited with each spoil load which may have differed from one block to the next, to differences in browse activity amongst the blocks, or to any number of other variables that might not have been adequately controlled such as topography and microclimate.  Following up on these results, it would be useful to conduct e additional experiments targeting key factors that this study suggests would most improve tree survival and growth on reclaimed mine sites.

## Conclusions

Forest productivity of post SMCRA grasslands can be restored using traditional silvicultural practices. In this study, we investigated the relative effectiveness of weed control only; weed control plus deep tillage; and weed control plus tillage and fertilization for restoring forest vegetation and productivity on previously-reclaimed mine sites in Ohio, Virginia, and West Virginia. Experimental plots were planted with eastern white pine, hybrid poplar, and mixed Appalachian hardwoods. After 4 years, deep tillage and weed control, when applied together, increased both survival and growth compared to the effect of weed control alone. The addition of fertilization did not increase survival or growth relative to the other treatments, but this may have occurred due to improper fertilizer placement. Silvicultural treatment effects exhibited high variability between locations and species, indicating that planted seedlings' survival and growth response to silvicultural treatments will, in many cases, be site specific.

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