Fourth-Year Tree Response to Three Levels of Silvicultural Input on Mined Lands[1]

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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 expenditures. 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 two tree species and a speices mix with potential for use in the reforestation of reclaimed surface mine lands in the Appalachians.

Methods and Materials

Background

This experiment employed a 3 x 3 x 3 factorial combination of silvicultural treatments, species and state location using a randomized complete block design (Fig. 1). The three silvicultural treatments studied were herbaceous weed control using herbicide, subsoil ripping, and fertilization. Experimental plots were established in Ohio, Virginia, and West Virginia on three separate sites in each state, providing three repetition blocks for each treatment-species-state combination. Species groups included Eastern white pine (*Pinus strobus*), hybrid poplar (*Populus* spp.) and a mix of native Appalachian hardwoods (Table 1). Plot locations were randomized within each block. 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).

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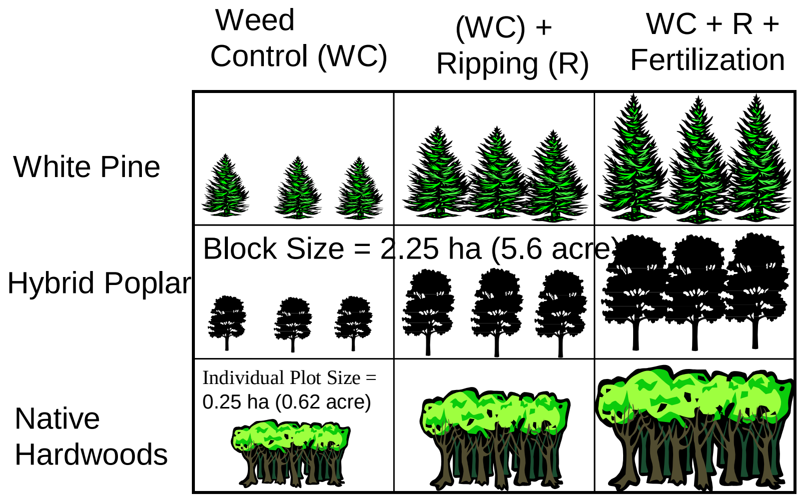

Figure 1. Hypothetical 3x3 layout of a single block of treatments. This series of plots was replicated 3 times in each of 3 states (VA, WV, and OH).

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

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 among 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 had 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 five 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).

Species Description

Eastern white pine has been commonly planted as a crop tree on southern Appalachian reclaimed surface mine lands (Torbert and Burger 2000). Hybrid poplar 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).

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, hardwoods were planted as 1-0 bare root seedlings and the planted hybrid poplars were approximately 20 cm-long stem cuttings. Species groups were planted in uniform plots and not intermixed with each other, though plots containing different species were adjacent to each other on the ground as a part of the three replication blocks in each state.. 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 broadcast across the study areas 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. Weed control treatment was constant across all study plots and was therefore a control variable rather than an experimental variable (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) using groundline diameter for D. 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 ($P < 0.10$). Multi-factor analysis was also performed to analyze species by treatment interaction and state effects. Multi-factor analysis involved comparing each possible silvicultural treatment-species combination, each silvicultural treatment-state combination, each species-state combination, and each silvicultural treatment-species-state combination with all of the other combinations in each category to determine any significant interaction effects among the experimental variables. Multi-factor analysis was performed using the fit model feature in JMP 7.0 with Tukey-Kramer HSD for mean separation.

Results

Tree Response to Treatments

Tree survival and growth means by silvicultural treatment across all states and species varied, but there were interaction effects (Table 2) among experimental variables that made statistical analysis of these overall means invalid. However, there were significant effects of silvicultural treatments on individual species groups as responses by species groups to the same silvicultural treatments differed (Table 3). Survival and growth of trees in Ohio, and growth of trees in Virginia, were 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 and growth were affected by species selection, state location and silvicultural treatment (Table 2). Survival and growth on all sites together were also affected by interactions of species with state and of state with treatment but only growth was affected by an interaction of species with silvicultural treatment (Table 2).

Table 2. Analysis of variance 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 survival and biomass index by treatment across all states and species. WC = weed control only; WC+R = weed control plus subsoil ripping; WC+R+F = weed control plus subsoil ripping and fertilization.

Treatment	Survival (%)	Biomass Index (cm^3)
WC	44	981
WC+R	64	4956
WC+R+F	52	4482

Survival

Survival was significantly affected by a variety of factors (Table 4). Hybrid poplars survived better than white pines in Virginia. Mixed hardwoods survived better than hybrid poplar in West Virginia. Mixed hardwoods and hybrid poplars survived better than white pines in Ohio. Across all states and treatments, mixed hardwoods survived better than white pines. Subsoil ripping improved survival of white pines and of all species groups aggregated together in Virginia. Subsoil ripping also improved survival of mixed hardwoods and hybrid poplars and of all species groups aggregated together in West Virginia, but the addition of fertilization with ripping to hybrid poplars reduced survival to the level of weed control alone. Subsoil ripping improved the survival of only hybrid poplars in Ohio, and only relative to the most intensive cultural treatment (weed control plus ripping and fertilization); this effect was not evident for an aggregate of all species groups.

Table 4. Mean percent survival of all replications by species, state, and treatment after four years.

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

*The same letter connecting treatment response data for each species means no significant difference at p = .10. 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.

Growth

Growth was also significantly affected by multiple factors (Table 5). Eastern white pine, mixed hardwoods and hybrid poplar grew equally well within their species groups under all silvicultural treatments in both Virginia and Ohio, as did Eastern white pine and mixed hardwoods in West Virginia. Hybrid poplar in West Virginia grew faster with the addition of subsoil ripping, both with and without fertilization, though the addition of fertilization to ripping did not significantly alter growth. 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.

Table 5. Mean biomass index [(groundline diameter)^2 x height] in cm^3 of all replications by species, state and treatment after four years.

	Tree Species							
Site and Treatment	**WP**		**MH**		**HP**		**Treatment Mean**	
Virginia								
WC	261.5	a	333.9	a	5163.9	a	**1919.8**	**a**
WC+R	411.8	a	184.5	a	11806.9	a	**4134.4**	**a**
WC+R+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**	**A**
West Virginia								
WC	233.1	a	31.4	a	1577.8	b	**614.1**	**a**
WC+R	604.5	a	150.4	a	27159.6	a	**9304.8**	**a**
WC+R+F	358.4	a	101.5	a	20837.7	a	**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+R	29.5	a	58.7	a	4201.3	a	**1429.8**	**a**
WC+R+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**	**A**
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 = .10. 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.

Interaction Effects

Table 2 indicated the existence of significant effects on survival and growth by interactions among various experimental factors. These interactions are graphically illustrated in Figures 2-6. Non-parallel lines indicate potentially significant interactions among factors beyond those normally expected from the effects of individual factors. Ripping, both with and without fertilization, increased West Virginia trees' survival (Fig. 2). Hybrid poplars were sensitive to fertilization in West Virginia (Fig. 3), as exhibited by decreased survival relative to ripping alone. Growth was most improved by ripping in West Virginia, where both of the ripping treatments had a significant influence on growth relative to weed control alone (Fig. 4). Hybrid poplar growth was greater in West Virginia than in Virginia, but none of the other species groups exhibited state-by-state growth differences (Fig. 5). Similarly, hybrid poplar growth across all states was positively influenced by both ripping treatments, relative to weed control alone (Fig. 6).

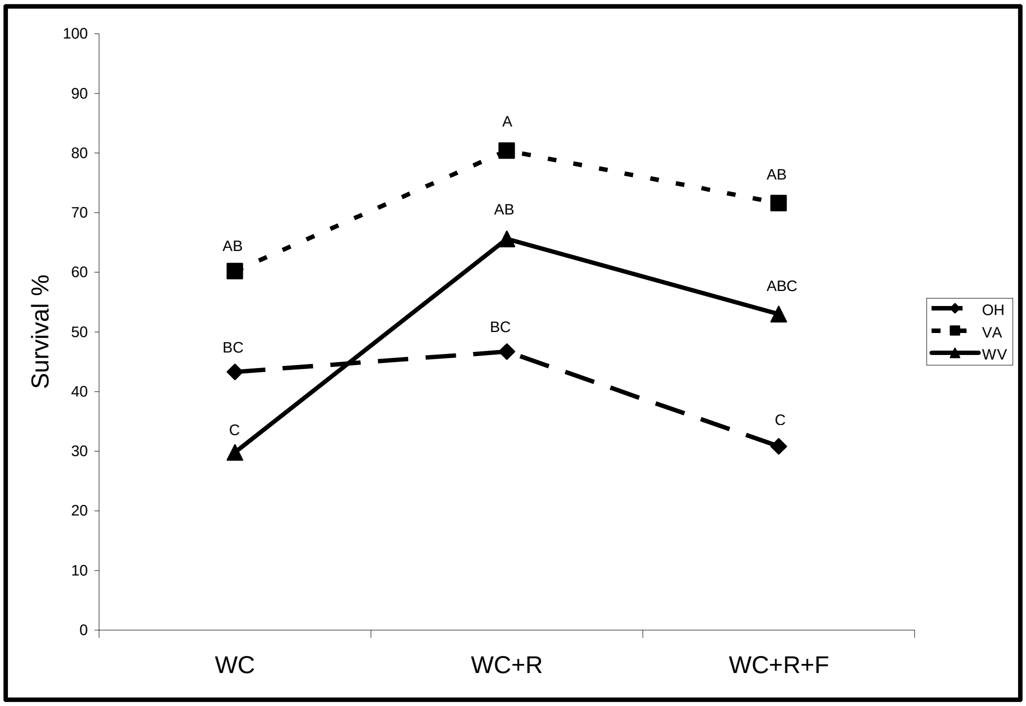

Figure 2. Interaction between silvicultural treatment and state location on percent survival after fourth year of growth. Data points with the same letter are not significantly different.

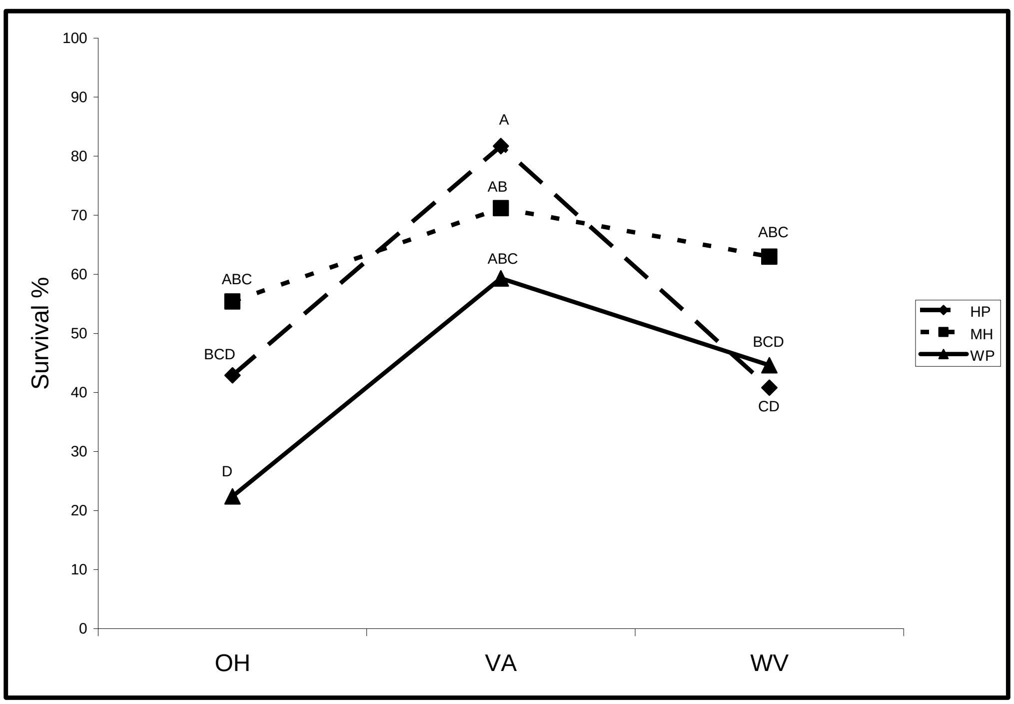

Figure 3. Interaction between state location and species group on percent survival after fourth year of growth. Data points with the same letter are not significantly different.

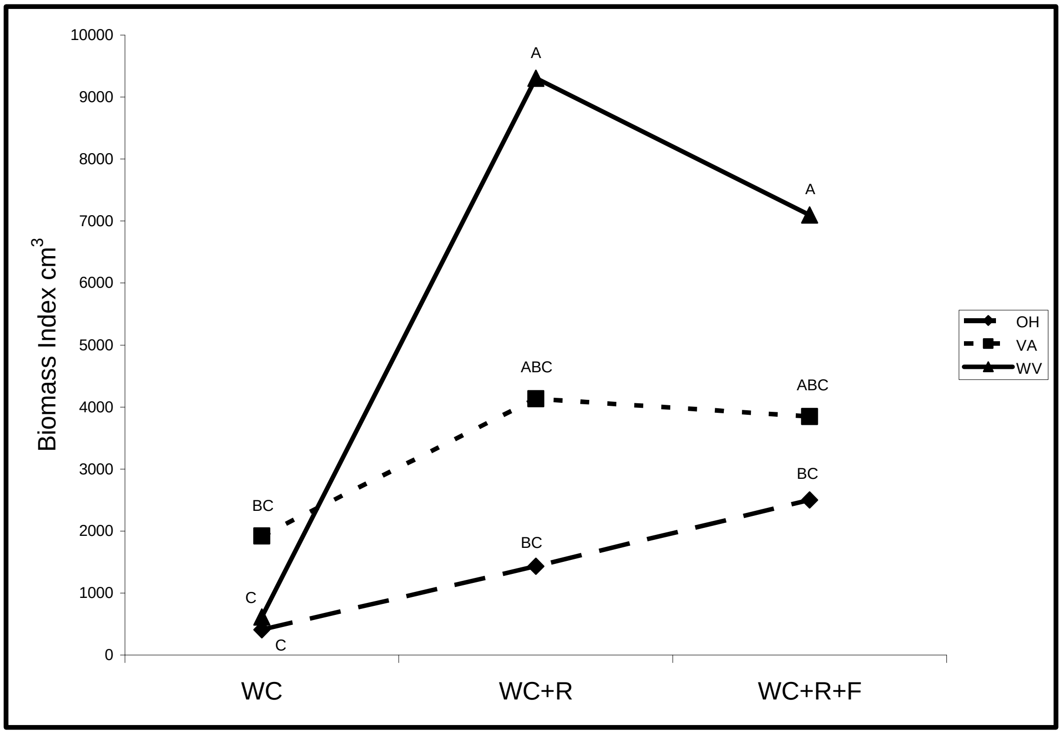

Figure 4. Interaction between silvicultural treatment and state location on biomass index after fourth year of growth. Data points with the same letter are not significantly different.

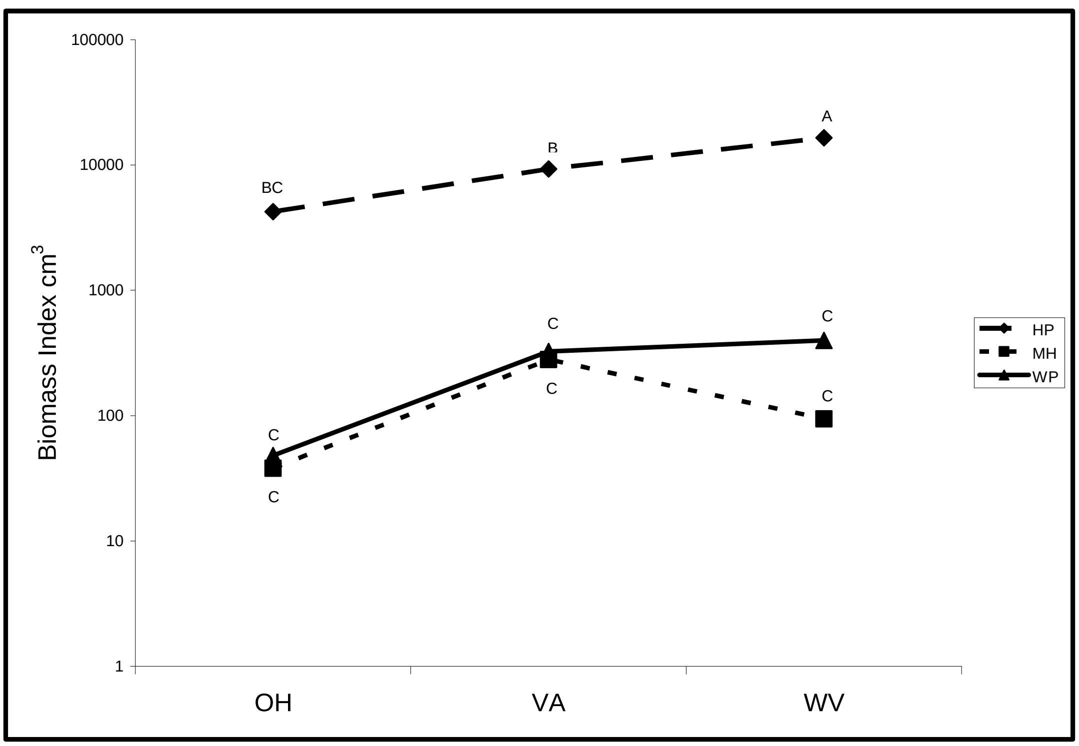

Figure 5. Interaction between state location and species group on biomass index after fourth year of growth. Data points with the same letter are not significantly different.

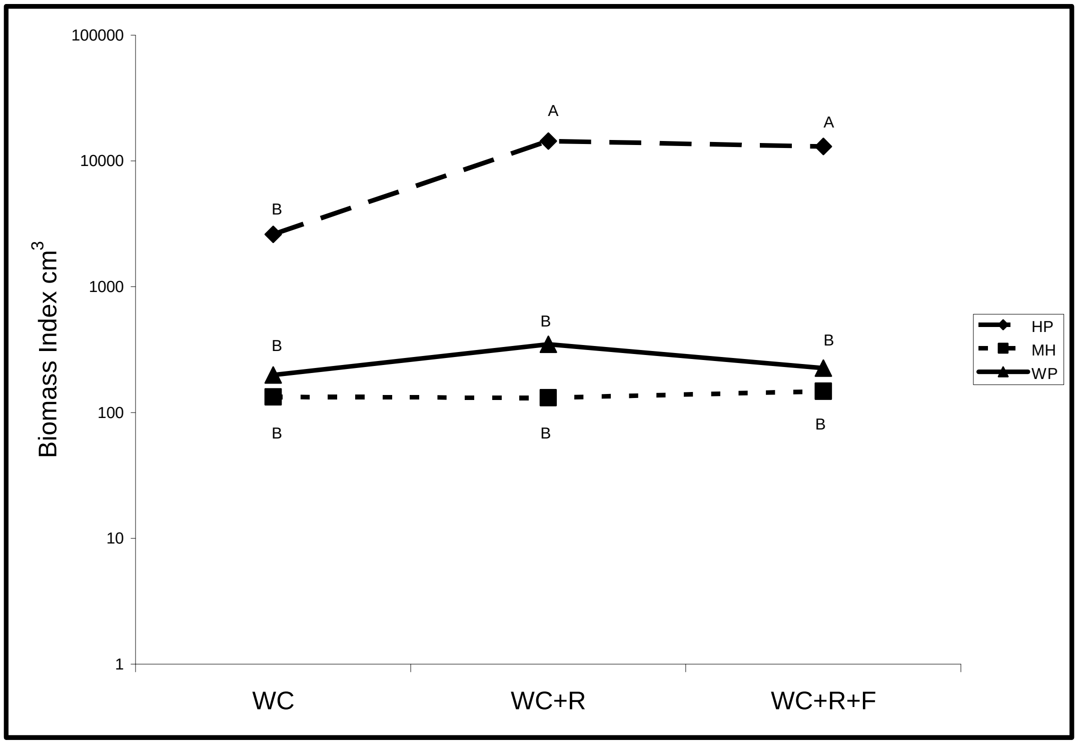

Figure 6. Interaction between silvicultural treatment and species group on biomass index after fourth year of growth. Data points with the same letter are not significantly different.

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. Hybrid poplar is in a class by itself in terms of early growth potential; these responses are similar to those reported for both mine soils (McGill et al. 2004) and natural soils (Van den Driessche 1999). This hybrid is especially useful for sequestering carbon or producing woody biomass at least for short-term planning horizons (Scott and Kuhn 2000).

West Virginia, with its shale-based, uncapped minesoils, produced nearly four 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 prior to tree establishment. 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 (Torbert et al. 1990).

The addition of ripping to herbaceous weed control as a silvicultural treatment produced consistently beneficial results. Ripping increased survival significantly in West Virginia for both mixed hardwoods and hybrid poplar. It also increased growth of hybrid poplar in West Virginia. Better survival and growth is a relatively common response when compacted mine soils are ripped (Philo et al. 1982). For our 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. Other studies have found fertilization to cause significant improvements in survival or growth if applied appropriately (Ramsey et al. 2001), but that result 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 observation 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 were 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 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 four 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.

Acknowledgments

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