Forest Productivity and Minesoil Development Under A White Pine Plantation Versus Natural Vegetation After 30 Years

by
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Abstract In 2000, the State of West Virginia passed legislation requiring commercial forest land as a preferred post-mining land use on surface coal mines, and especially on those sites where mountaintop removal mining is occurring and valley fills are being constructed. Due to West Virginia's mountainous terrain, most future surface mine permits will be impacted by this change in post-mining land use. Therefore, interest has been renewed into studies examining forest productivity and minesoil development on areas planted in trees. Since fresh geologic materials in minesoils undergo rapid pedogenic changes, long-term studies may provide valuable insight into tree growth, plant successional changes, and soil development over time. In summer of 2000, soil development and forest productivity were evaluated on a 30-year-old (pre-SMCRA) surface mine in northern West Virginia that had been planted with white pine (*Pinus strobus* L.). The site offered a unique research opportunity in that one-half of the site was planted to white pine, while the other half was left to natural revegetation. Canopy tree species composition, density, basal area, and height, along with species composition and density of woody understory seedlings, were evaluated in the pine plantation and on the naturally revegetated site. On each site, three soil pits were dug, the minesoils were classified, and soil samples were taken from each described horizon to determine physical and chemical properties. Forest productivity, including productivity of volunteer hardwoods, was much greater on the pine planted site than on the naturally revegetated site. Species composition of woody regeneration in the understory showed that both sites will revert to mixed hardwoods similar to the surrounding forest via natural succession. Minesoils on both sites experienced rapid soil development during the 30-year post-mining period. All six minesoil profiles had well developed Bw horizons and would have been classified as Inceptisols. Minesoil development was better on the naturally revegetated site possibly due to the difference in ground cover type.

Additional Key Words: Minesoil Properties, Reforestation, Revegetation, Tree Planting,

Introduction

Surface coal mining disturbed approximately 1.5 million ha (3.7 million ac) between 1930 and 1971 in the United States (Paone et al. 1978). In Appalachia, the vast majority of surface mined land was originally forest land. Laws were passed in Ohio, Pennsylvania, and West Virginia during the late 1930s and 1940s requiring mine operators to register with the state and pay bonds to ensure reclamation after mining. Reclamation prescribed in these early laws directed soil, subsoil, and overburden (the geologic material overlying the coal) be used to refill the excavated area. Backfilling and leveling the land was specified, and then trees and shrubs were to be planted in the regraded areas.

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Studies of surface mine revegetation with trees began in the 1920s and reports on planting success began in the 1940s. Black locust (*Robinia pseudo-acacia* L.) was the most extensively studied and successful species (Brown and Tryon 1960). Other species such as autumn olive (*Elaeagnus umbellata* Thumb.), Virginia pine (*Pinus virginiana* Mill.), red pine (*P. resinosa* Ait.), and white pine (*Pinus strobus* L.) grew well in many early studies (Brown 1962, Chapman 1947, Minkler 1941, Potter et al. 1955, Tryon 1952). Hardwoods like oaks (*Quercus* spp.) and cherry (*Prunus* spp.) failed to grow, usually because the trees sustained rodent damage. It has been estimated that approximately 60% of the land disturbed between 1930 and 1971 was reclaimed in some fashion by industry (Keys et al. 1971). This reclamation probably included backfilling and some type of tree or grass planting.

As an example of some of this early work, the following was recorded in 1967 by Al Beaty, District Conservationist, USDA Soil Conservation Service, Preston County, WV (where the research in this paper took place).

“In the early 1950s, the strip mine operator released his bond to the Monongahela Soil Conservation District. The district was then responsible for reclaiming the surface mine area. As soon as the bond was transferred, the Department of Natural Resources released the surface mine operator from reclamation liability. In the beginning, the four-row system was used: four rows of white pine, then four rows of black locust, then four rows of Scotch or Virginia pine (red pine was used at higher elevations). The conifers grew at a good rate, but there was very little ground cover between trees. It takes several years for a pine needle litter layer to form. Under these plantings, the ground was still bare and gully erosion resulted, so they started planting more locust.”

“The first plantings were done on a 6' x 7' spacing at a rate of 1000 trees per acre, at a cost of $40 per acre. At the end of the second growing season after planting, the area was inspected by the District Supervisor, a representative from the Soil Conservation Service, and the strip mine inspector. In order to release the area, there had to be a 60% survival rate on the planting, and there could be no bare areas larger than one quarter acre.”

“The reason for the success of these early plantings was due to this being the first cut for coal. Generally, there would only be 15 to 20 feet of overburden removed above the coal, and highwalls were usually under 30 feet. The pH of this material was good. The highwalls were left and generally the bench filled with water, thereby controlling water flow offsite.”

“In the late 1950s, locust, black alder, and autumn olive were planted along with birdsfoot trefoil and fescue, orchardgrass or timothy. On good sites with level areas, conifers were still planted. The soil pH of these areas was between 5.0 and 5.5. In the 1960s, subsequent cuts were made on these areas (thereby destroying much of the reforestation work previously done) with higher highwalls. The upside down method of strip mining was used, where the soil was thrown off first and ended up underneath with rock on the top. The pH of these spoil areas was under 4.0. Plantings were getting a survival rate of 10%. Liming (50 tons/ac) and fertilizing (1000 pounds of 10-10-10/ac) gave a 90% survival rate on plantings. From 1955 to 1965, about 1,000 acres were planted each year in the district, for a total of 9,567 acres” (see also Mellinger et al. 1966). Oliverio (1972) estimated that between 1955 and 1969, 2736 contracts were signed between districts and coal operators for a total of 47,995 acres.”

During ensuing decades and by 1977, laws and regulations governing surface mine reclamation in the eastern U.S. evolved into seeding grasses and legumes rather than establishing trees (Torbert and Burger 2000). The rationale for this change was that forage species controlled erosion, provided a quick economic return to land owners through haying or grazing of livestock, and was aesthetically pleasing (Vogel 1977). Soil Conservation Districts also were not contracted by coal operators to conduct land reclamation after 1970. Therefore, these laws have generally hindered tree planting because they permit partial release of reclamation bonds as soon as the ground cover requirement is met. The cover requirement is achieved by herbaceous plants, and planting of woody plants is an added reclamation expense to mining companies. In addition, the herbaceous cover competed with planted tree seedlings resulting in high mortality.

Since 1977, most surface coal operators in West Virginia have revegetated their mined areas with grasses and legumes. Fewer operations established tree plantings or wildlife habitat plantings. But there has been a gradual shift by coal companies in some regions to re-establish sustainable forests on reclaimed mines (Torbert and Burger 2000).

Eastern white pine occurs naturally throughout the eastern United States and especially in the coal region of northern West Virginia. It is moderately tolerant of shade, makes rapid juvenile growth, and can produce merchantable sawtimber in 35 to 40 years (Andrews et al. 1998). It is most closely associated with well-drained, sandy soils but also grows on loamy and silty soils, whether drainage is good or poor. Optimum pH for growth is 4.5 to 6.0, but it will grow at higher pH than most pines (Bennett et al. 1978). Shallow rooting depths, high soluble salt contents, extremes of pH, poor drainage, and soil compaction are common soil-limiting factors that negatively affect tree growth on reclaimed mined lands (Andrews et al. 1998, Bussler et al. 1984, Torbert and Burger 2000, Zeleznik and Skousen 1996).

A number of studies have determined minesoil properties on abandoned sites (Ciolkosz et al. 1985, Grube et al. 1982, Johnson and Skousen 1995, Sencindiver et al. 1989, Singh et al. 1982, Smith et al. 1971) and on reclaimed sites (Ammons et al. 1991, Bussler et al. 1984, Haering et al. 1993, Roberts et al. 1988, Thurman and Sencindiver 1986) in the eastern United States. However, very few studies make a comparison of minesoil development on adjacent sites which are covered with different vegetation cover types. The objective of this study was to determine forest productivity and minesoil development after 30 years on adjacent sites under two different vegetation types: a white pine plantation and natural revegetation.

Materials and Methods

Study Site

The study area was 5 km southeast of Brandonville, Preston County, WV. Topography in the area was gently rolling to steep with dominant land uses being pasture and forestland. The study site was located on a 30-year-old (pre-SMCRA) minesite. The coal bed mined was the Lower Freeport (Allegheny Group of the Pennsylvanian System) and overburden at the site was a mixture of sandstone and shale. The disturbed area examined for this study was approximately 80 m wide by 500 m long. The minesoil bench was gently sloping (3 to 5%) up to an approximate 12 m highwall. The surrounding undisturbed land area was composed of mixed hardwood forest.

The study site offered a unique research opportunity in that one-half had been planted to white pine (*Pinus strobus* L.), while the other half was left to natural regeneration. The white pine trees in the plantation areas were planted in a four-row system on a 2 m by 2.5 m spacing with an 8-m-wide open buffer strip between each group of four rows for a total planting density of 1000 trees/ha. The age of the planted white pine trees was determined to be 27 to 29 years old in the summer of 2000. Although other tree species were found in the buffer zones between the pine rows, they appeared to be volunteer trees rather than planted trees due to their younger age and random spacing.

The naturally revegetated side of the study area had received no cultural treatments during the 30-year post-mining period. The dominant ground cover was broomsedge (*Andropogon virginicus* L.) and poverty grass (*Danthonia spicata* (L.) Beauv.) with scattered volunteer tree species. Approximately 30% of this area was devoid of living vegetation ground cover and covered by a surface layer of rock fragments.

Sampling and Measuring Methods

After the boundaries of the two study areas were established, a 20 x 20-meter grid was superimposed on the sites. A 20-m buffer strip was maintained on all sides of each site. Three sampling/measuring points were located at the intersection of randomly determined grid points within both the planted and naturally revegetated areas. At each of these measuring points, forest productivity parameters were measured using fixed area plots. Forest vegetation was measured using three size groups: canopy trees were defined as those >10 cm dbh (diameter breast height = 1.4 m); understory trees were those <10 cm dbh and >0.5 m in height; and woody regeneration were tree seedlings <0.5 m in height. All canopy trees within a 500 m^2 circular plot were measured by species for density, dbh, and total height. In addition, early height growth was measured for the planted white pine trees by measuring the internode lengths for the first 20 years of growth. The total height and internode lengths were measured on felled trees at the end of the summer when the site was harvested by clearcutting. The density of the understory trees was also measured within the same 500 m^2 circular plot. Density by species of woody regeneration was measured using four 3-m^2 circular plots located in cardinal directions 4 m from the main plot center.

After forest vegetation measurements were completed, a soil pit was excavated by hand using pick, shovel, and pry-bar at the center of each main plot. Due to the extreme rockiness (boulders) in the subsoil, all soil pits were less than 1 m deep, but they all were deep enough to be below the pedogenic weathered zone and extended into structureless parent material. Each soil profile was described using standard soil survey procedures (Soil Survey Division Staff 1993). Bulk soil samples were collected from each horizon for determining soil pH (McLean 1982), soluble salts as measured by electrical conductivity (Rhoades 1982), and particle-size distribution by pipette method (Gee and Bauder 1986). Undisturbed soil clods were extracted to determine bulk density in the lower soil horizons using a non-polar liquid method (Sobek et al. 1978). Due to granular structure in the surface A horizons, bulk density for the A horizons was determined using an excavation method (Blake and Hartge 1986a). Bulk density of the <2 mm soil fraction was determined by correcting (subtracting) for the weight and volume of rock fragments. Total porosity of soils was determined using the following equation (Hillel 1980):

$$TP = (1 - BD/PD) \times 100 \qquad (1)$$

where TP is the percent total porosity by volume, BD is the soil's bulk density, and PD is the soil's particle density. Particle density of soil solids was determined by the pycnometer method (Blake and Hartge 1986b).

Results and Discussion

Woody Species Diversity

Planted and naturally revegetated sites had the same number of woody species on average (Table 1).

Table 1. Forest productivity for planted and naturally revegetated sites.

	Canopy Trees > 10 cm dbh				Understory	Woody
Species	Density	Basal Area	Avg dbh	Avg Height	<10cm dbh, >0.5m ht.	Regen <0.5m ht
	trees/ha	m^2/hacm	m		trees/ha	trees/ha
Planted						
WP[1]	560	26.0	23.6	18.5	*[2]	2,100
BC	120	3.1	15.0	17.6	153	8,280
BL	73	3.9	34.8	17.2	13	*
RM	7	0.1	16.2	16.8	*	54,150
AO	*	*	*	*	167	4,240
RO	*	*	*	*	40	1,050
BB	*	*	*	*	7	860
FC	5	0.6	18.3	17.1	*	*
Totals	765	33.7			380	70,680
Naturally Revegetated						
BC	27	0.3	11.0	5.6	60	1,590
BL	20	0.5	17.1	10.1	40	540
RM	13	0.1	11.7	7.2	326	4,780
AO	*	*	*	*	44	*
RO	*	*	*	*	46	3,190
BB	25	0.4	11.9	9.0	346	8,920
SW	*	*	*	*	*	260
Totals	85	1.3			862	19,280

[1]Species abbreviations: WP=White Pine (*Pinus strobus* L.), BC=Black Cherry (*Prunus serotina* Ehrh.), BL=Black Locust (*Robinia pseudo-acacia* L.), RM=Red Maple (*Acer rubrum* L.), AO=Autumn Olive (*Elaeagnus umbellata* Thunb.), RO=Red Oak (*Quercus rubra* L.), BB=Black Birch (*Betula lenta* L.), FC=Fire Cherry (*Prunus pensylvanica* L. f.), SW=Sourwood (*Oxydendrum arboreum* (L.) DC).
[2]Not found in plot.

Invasion of volunteer species into the white pine planted site contributed to its high species richness. All volunteer species found on the planted site were common pioneer species of disturbed sites having seeds that are dispersed by either wind or animals. Most of the volunteer trees were found in the buffer zones between the four-row plantings although some were found growing in the pine rows where openings had occurred due to pine seedling mortality. Many of these same species have been found in previous studies (Andrews et al. 1998, Zeleznik and Skousen 1996) to be common invaders into white pine plantations. For the most part, the same species were found in the planted and naturally revegetated sites (Table 1) emphasizing the influence of the surrounding hardwood forest as a seed source for natural succession.

Forest Productivity

Overall tree stocking and composition was much higher on the planted than naturally revegetated site as exhibited by basal area, average diameter, and average height of canopy trees (Table 1). Total basal area was more than 25 times greater on the white pine planted site than on the naturally revegetated site. Even productivity of volunteer hardwood trees was higher in the white pine site than on the naturally revegetated site.

Basal area for volunteer hardwoods was more than five times higher on the pine planted site than on the naturally revegetated site (Table 1). The better volunteer hardwood tree growth in the white pine site may be due to favorable microclimate created by white pine. The

Table 2. Average of three minesoil profile descriptions in both planted and naturally revegetated sites.

	Horizon	Depth (cm)	Color	Texture	Structure[1]	Rooting	Clay Films	Rock Frag (%)
Planted								
	A	0-6	10YR 3/3	Loam	Wk, Gran	com,fine-med	none	30
	Bw	6-27	2.5YR 4/3	Loam	Mod, Sbk	few, fine	few, patchy	60
	BC	27-50	2.5YR 4/3	Loam	Wk, Sbk	few, fine	v.few, patchy	65
	C	50-76	2.5YR 4/3	Loam	Sl, massive	none	none	75
Naturally Revegetated								
	A	0-11	10YR 3/3	Loam	Str, Gran	many,fine	none	25
	Bw	11-39	10YR 5/3	Loam	Mod, Sbk	com, fine	few, patchy	45
	BC	39-57	10YR 5/3	Loam	Wk, Sbk	few, fine	v.few, patchy	60
	C	57-78+	10YR 5/3	Loam	Sl, massive	none	none	70

[1]Structure: Wk=weak, Mod=moderate, Sl=slight; Gran=granular, Sbk=subangular blocky.

combination of partial shading and presence of pine needle mulch may have provided cooler, moister soil conditions and lower competition from grasses and herbaceous cover thereby favoring hardwood seedling germination and establishment. Even the woody regeneration as measured by density of seedlings <0.5 m in height was almost four times higher on the pine planted site than on the naturally revegetated site (Table 1). Table 1 emphasizes that early tree growth including production of hardwoods was greatly enhanced by the planting of white pine in this study. Examination of woody regeneration indicates that, barring supplemental plantings, the white pine planted site will revert by natural succession to the mixed hardwood forest type native to the area.

Minesoil Properties and Soil Development

Soil Profiles. Selected soil parameters related to soil development and classification are shown in Table 2. The number of horizons and horizon sequence was similar in all six minesoil profiles examined in this study. All minesoil profiles on both planted and naturally revegetated sites had A horizons with granular structure. All minesoil profiles also had Bw horizons. Two out of three Bw horizons on both planted and naturally revegetated minesoils exhibited patchy discontinuous clay films in pores. Other studies (Ciolkosz et al.1985, Gorman and Sencindiver 1999) also noticed patchy discontinuous clay films forming in young minesoils <30 years old.

All minesoil profiles also contained BC transitional horizons distinguished by weak structure development at the lower depths. One out of three profiles on both the planted and naturally revegetated sites also showed very few patchy discontinuous clay films in the BC horizon. Surprisingly, average A horizon development and total solum depth (top of C horizon) was greater in minesoils on the naturally revegetated site (Table 2) despite its lower level of plant productivity. One possible explanation for this could be the difference in vegetation type. Grasses were the dominant vegetation type on the naturally revegetated site during the 30-year post-mining period, while woody tree species dominated the planted site during this period.

Surface A horizons forming under grass vegetation in the naturally revegetated site in addition to having thicker development also had stronger structure development (Table 2). Plant roots were more prolific and found at greater depths in the naturally revegetated minesoil (Table 2) compared to the planted minesoil. Thomas and Jansen (1985) also found more rapid soil structure development with grass vegetation compared to trees. Density and depth of plant rooting and its effects on soil structure development may explain the thicker solum and Bw horizon development under the grass vegetation on the naturally revegetated site. Another possible explanation for deeper soil development on the naturally revegetated site may be warmer soil temperatures and more rapid weathering rates as a result of increased solar radiation due to sparse vegetation canopy cover.

All minesoil profiles examined in this study, on both planted and naturally revegetated sites, would meet the criteria to be classified as Inceptisols. Current family-level classification under *Soil Taxonomy* (Soil Survey Staff 1998) would be loamy-skeletal, mixed, active, mesic Typic Dystrudepts.

Soil Properties

pH. Soil reaction as measured by pH was acidic with all horizons having pH values ranging from 3.8 to 4.8 (Table 3). Johnson and Skousen (1995) found that tree establishment and growth was greater on acidic minesoils in this pH range because of decreased competition from herbaceous cover. Soil pH appeared to be slightly higher in the subsoil of minesoils on the planted site. This higher pH may be a result of more shale in the parent material on the planted site as evidenced by the darker gray 2.5Y 4/3 color in the subsoil compared to the lighter brownish 10YR 5/3 color found in the subsoil of the naturally revegetated site (Table 2).

EC. Soluble salts, as measured by electrical conductivity (EC), appeared to be slightly higher in the planted minesoil than on the naturally revegetated minesoil (Table 3). Organic acids, produced by pine needle decomposition, may have caused higher EC in the pine plantation A horizon. Higher average EC in the subsoil of the pine plantation may be due to alkalinity from higher shale content. Values of EC for all horizons on both sites were relatively low and would have no adverse effects on plant growth.

Bulk Density and Total Porosity. Average bulk density appeared to be lower and total porosity higher in A and Bw horizons in the naturally revegetated minesoil versus the planted minesoil (Table 4). This may be a result of stronger structure development and the lower percentage of rock fragments found in these horizons on the naturally revegetated site (Table 2). This effect of plant rooting and structure development is most evident in differences in average <2 mm bulk density values for A and Bw horizons on the two sites (Table 4). Lower bulk density and higher total porosity should result in better infiltration, drainage, and aeration in the surface horizons of the naturally revegetated site.

Particle Size Distribution. On average, more sand and less clay were found in A horizons than B horizons on both sites (Table 5). The highest average clay percentage was found in the B horizons. This, along with the patchy discontinuous clay films found in these horizons (Table 2), suggests that these minesoils may be in the early stages of argillic horizon formation. In a previous study, Gorman and Sencindiver (1999) noticed similar evidence of weathering and eluviation in the surface horizons of a nine-year-old minesoil developing from similar parent material.

Conclusions

Forest productivity was much greater on the white pine planted site than on the naturally revegetated site. Even productivity of invading hardwood species was higher on the planted site compared to the naturally revegetated site. This was possibly due to creation of a more favorable microclimate for seedling germination and establishment as well as less herbaceous competition as a result of the pine canopy. Species composition of woody regeneration in the understory reveals that both sites will revert to mixed hardwoods similar to the surrounding forest via natural succession.

Rapid soil development had occurred on both sites during the 30-year post-mining period. All soil profiles examined had well developed A horizons and Bw horizons. Two out of three profiles exhibited patchy discontinuous clay films in B horizons indicating clay movement. All minesoil profiles had enough soil development to classify as Inceptisols. Soil development was greater (thicker A and Bw horizons, stronger structure, lower bulk density, and deeper solums) on the naturally revegetated site compared to the pine planted site. Better soil development on the naturally revegetated site may have been due to the type of vegetation ground cover. Grasses, which dominated the naturally revegetated site during the 30-year post-mining period, generally produce quicker and better structure development in surface horizons than trees.

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Table 3. Minesoil pH and electrical conductivity (EC) values for planted (WP) and naturally revegetated (NR) sites in West Virginia.

Horizon	pH		EC (dS/cm)	
	WP	NR	WP	NR
A	3.8 ± 0.2	4.0 ± 0.1	0.19 ± .02	0.07 ± .02
Bw	4.8 ± 1.0	3.9 ± 0.1	0.11 ± .03	0.07 ± .02
BC	4.8 ± 0.8	4.0 ± 0.1	0.10 ± .03	0.08 ± .01
C	4.5 ± 0.7	3.9 ± 0.1	0.15 ± .07	0.09 ± .03

Table 4. Bulk Density (with and without rock fragments) and total porosity of minesoils under planted (WP) and naturally revegetated (NR) sites in West Virginia.

Horizon	Bulk Density		Bulk Density <2 mm		Total Porosity	
	WP	NR	WP	NR	WP	NR
	Mg/m^3				%	
A	1.57 ± .06	1.29 ± .13	1.13 ± .06	0.87 ± .08	41 ± 1.3	51 ± 5.4
Bw	1.95 ± .06	1.89 ± .11	1.58 ± .08	1.40 ± .11	24 ± 1.2	27 ± 5.7
BC	1.82 ± .17	1.77 ± .14	1.45 ± .12	1.53 ± .05	28 ± 5.8	32 ± 5.3
C	1.75 ± .13	1.68 ± .08	1.53 ± .05	1.55 ± .04	32 ± 4.5	35 ± 2.9

Table 5. Percentages of sand, silt and clay, and texture for minesoils under planted (WP) and naturally revegetated (NR) sites in West Virginia.

Horizon	Sand		Silt		Clay		Texture	
	WP	NR	WP	NR	WP	NR	WP	NR
	%							
A	46 ± 5.1	43 ± 3.8	39 ± 4.6	38 ± 1.1	15 ± 0.7	19 ± 2.7	Loam	Loam
Bw	41 ± 7.7	37 ± 0.5	41 ± 6.4	42 ± 1.5	18 ± 1.4	21 ± 1.5	Loam	Loam
BC	31 ± 3.2	36 ± 2.4	48 ± 1.9	44 ± 2.5	21 ± 1.7	20 ± 0.2	Loam	Loam
C	35 ± 9.5	37 ± 2.4	46 ± 6.1	42 ± 2.0	19 ± 3.6	21 ± 0.8	Loam	Loam

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