FOREST AND SITE PRODUCTIVITY ON PRE-SMCRA MINED LAND[1]

by

J. A. Rodrigue[2] and J.A. Burger

Abstract. Citizens and landowners in the midwestern and eastern coal mining region are concerned that current reclamation procedures are not achieving forest productivity levels required by the Surface Mining Control and Reclamation Act of 1977 (SMCRA). To provide a benchmark for comparison, we investigated the effects of mining and reclamation practices used prior to the passage of SMCRA on forest and site productivity. Forest and site productivity of fourteen mined and eight natural sites in the eastern and midwestern coalfield regions were compared. Results indicate that forest productivity varied among sites depending on the species planted, while site productivity was, on average, similar to non-mined site productivity. Mined sites with site productivity levels similar to non-mined sites shared similar soil properties. Differences in mined and non-mined site productivity levels are reflected by differences in soil properties. Forests on pre-SMCRA mined lands are productive, and valuable. They should provide insight into the impacts of current reclamation practices on reforestation success and potential forest productivity.

Additional Key Words: reforestation, mined land, reclamation

Introduction

Surface mining has drastically disturbed land, forests, and waterways of the midwestern and eastern US for close to a century. Prior to the enactment of the Surface Mining Control and Reclamation Act (SMCRA) in 1977, high levels of land disturbance by surface mining prompted some mine operators, landowners, and surrounding communities to reclaim mined areas (DenUyl, 1955). Many states with mining activity enacted regulations to control the mining and reclamation process (Davidson, 1981; Sandusky, 1980). In the midwestern and eastern states, most sites were reclaimed to forests through the planting of trees. The productivity of sites reclaimed with trees decades ago is still largely unknown. Even though many mined sites had the potential to develop into productive forests, many environmental problems remained, including erosion, degraded water quality, toxic spoils, uneven landscapes, acid drainage, highwalls and subsidence.

SMCRA was enacted to address human safety, land productivity, and environmental problems that occurred during mining and reclamation. However, in the process of meeting these objectives, disincentives to reforest mined land were created, and the post-mining landscape is commonly unproductive for forestry land uses (Burger, 1999). Post-law emphasis was placed on water quality and erosion at the expense of site productivity and reforestation (Boyce, 1999). The Code of Federal Regulations, 30, Mineral Resources (1997) interpreting SMCRA requires that states restore disturbed land to conditions that are capable of supporting the uses which they were capable of supporting before mining (715.13(a)). However, current reclamation in the Appalachian region results in mine soils that are usually thin, alkaline, highly compacted, and covered with exotic competitive grasses. These conditions make it difficult to achieve bond release requirements related to forestry post-mining land uses. For example, Burger et al. (2000) reported eleven-year results of a test planting of three pine species on a pre-SMCRA mined site and a post-

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SMCRA mined site. Trees planted on the pre-SMCRA mined site were planted on the flat bench that remained after contour coal extraction, while the post-SMCRA mined site was reclaimed to its "approximate original contour." The height and diameter growth of all three pine species (loblolly (*Pinus taeda L.*), Virginia (*Pinus virginiana Mill.*), and white (*Pinus strobes L.*)) was greater on the pre-SMCRA mined sites than the post-SMCRA mined sites. The average height of all species was 40 cm taller on the pre-law site after 5 years, and 42 cm taller after 11 years. Though site index estimates were similar across sites for loblolly pine, site index for white pine, a species better suited for the region, was much higher on the pre-law site. Projecting the pine growth rates to a harvest age of 20 years indicates that stumpage value on the post-SMCRA site will be approximately half that on the pre-SMCRA site.

The lack of productivity standards for reclaiming forestland allows mined land to be degraded from its original level of productivity. Current practice in most Appalachian states allows the operator to choose the rock overburden that is placed on the surface as long as it supports herbaceous ground cover and allows a minimum number of trees to survive for the bond period. Research has shown that the type of overburden suitable for the temporary ground cover is not necessarily the best choice for long-term forest uses (Torbert, 1995). Overburden selected for placement on the surface should be chosen for the permanent plant community and the specified post mining land use (Boyce, 1999). On Midwestern sites where topsoil can be stored and replaced, grading of the subsoil and topsoil can also create conditions unfavorable for tree growth and establishment, causing increased erosion, and poor root penetration (Pope, 1989).

We suggest that forestry post-mining land uses should also meet a productivity standard in order to ensure that the land is restored to its original productivity as the spirit of the law requires. Mature forests on older reclaimed mined sites can be used to predict the potential productivity of mined land reclaimed for forestry. Midwestern and eastern sites mined and re-vegetated under pre-law conditions currently support forests growing across a wide range of environmental conditions (Burger et al., 1998; Andrews, 1992; Plass, 1982). We evaluated both site and forest productivity on these pre-SMCRA mined sites and compared productivity levels to that on non-mined land. The first productivity estimate, site productivity, is a function of soil, geologic, topographic and climatic factors. It is commonly estimated using site index (SI), which is the average height of co-dominant canopy trees projected to age 50. To make site productivity comparisons between different species and stands it is commonly standardized to a single species. Site productivity estimates reflect soil and site characteristics while removing the effect of tree species growth differences, stand ages, and stocking levels. Another productivity estimate, forest productivity, is a reflection of management techniques as well as soil and site quality. It takes into account management activities in addition to inherent site conditions. Fertilization, drainage, changes of species, tree spacing, and use of genetically altered plants are all examples of management practices that influence forest productivity. Typically forest productivity is estimated by the mean annual increment (MAI) of commercially valuable wood produced per unit area.

Our objective was to measure the productivity of reforested surface mines and native non-mined forest, and to develop an understanding of the relationships between forest and site productivity. Miners and reclamationists are in the unique situation of being able to influence the future forest and site productivity of reclaimed sites. A better understanding of the reclamation process, mineland site factors, and the relationship between forest and site productivity will increase the quality of reclamation and the productivity of restored forests.

Methods

Site Selection and Layout

We studied fourteen forested sites on reclaimed surface mined lands across 7 states within the midwestern and eastern coal fields (Figure 1). The sites ranged from 20 to 55 years old and had 0.8 to 3 hectares of contiguous forest cover. The overstory species composition ranged from pure hardwood and conifer stands to mixed conifer and hardwood stands (Table 1). These sites also covered a spectrum of spoil types. Sites selected were chosen to represent a cross-section of stand and site conditions such as different mining type, canopy species composition, and stand age.

Within each geographic region (e.g. southern Illinois) a native forest reference site representing the species composition and productivity of regional forests was located and measured. The reference site was chosen in close proximity (usually adjacent to or within a few kilometers of) the sampled mined sites.

Table 1: Mined and non-mined site and forest productivity. Note: * represent significant differences between mined and non-mined sites at a 0.1 alpha level. † represent average age of trees measured on non-mined reference sites.

State	Site	History	Canopy Type	Stand Age	SI White Oak meters (feet)	MAI m3/ha (ft3/ac)
Illinois	1	Mined	White Oak/ T. Poplar	54	28.0 (92)	6.2 (88)
	2	Mined	Cottonwood	43	24.2 (80)	7.3 (105)
	3	***Non-mined***	***Scarlet Oak/R. Maple***	***43†***	***27.7(89)***	***5.9 (84)***
Indiana	1	Mined	Pitch Pine	55	23.4 (77)	4.4 (62)
	2	Mined	Pitch Pine/Hardwoods	50	24.2 (79)	3.3 (47)
	3	***Non-mined***	***Oak/T. Poplar***	***40†***	***25.5 (84)***	***5.4 (77)***
Kentucky	1	Mined	Mixed Hwd	35	22.7 (74)	6.6 (94)*
	2	Mined	Mixed Hwd	35	25.4 (83)	7.6 (109)*
	3	Mined	W. Pine/Lob. Pine	40	25.0 (82)	9.3 (133)*
	4	***Non-mined***	***Oak/T.Poplar***	***52†***	***23.8 (78)***	***3.6 (51)***
	5	Mined	Loblolly Pine	33	23.8 (78)	10.7 (153)*
Ohio	1	Mined	Mixed Hwd	50	25.1 (82)	5.0 (71)
	2	***Non-mined***	***Oak/T.Poplar***	***59†***	***23.1 (76)***	***4.0 (58)***
	3	Mined	Mixed Hwd	50	26.8 (88)	6.1 (88)*
West Virginia	1	Mined	White Pine	38	16.8 (55)*	3.7 (52)*
(North)	***2***	***Non-mined***	***Oak/T.Poplar***	***62†***	***24.7 (81)***	***4.8 (69)***
West Virginia	3	Mined	White Pine	28	28.7 (94)	12.1 (173)*
(South)	***4***	***Non-mined***	***Oak/T. Poplar***	***60†***	***25.9 (85)***	***4.8 (68)***
Pennsylvania	1	Mined	W. Pine/Scots Pine	40	20.3 (67)*	5.7 (81)
	2	***Non-mined***	***Oak/T.Poplar/Cherry***	***62†***	***24.8 (81)***	***4.4 (63)***
Virginia	1	Mined	White Pine	20	25.2 (83)	6.2 (89)
	2	***Non-mined***	***Oak/ T. Poplar***	***72†***	***26.9 (88)***	***7.8 (111)***

Figure 1: Location of study sites in the midwestern and Appalachian coalfields regions.

Reference sites supported mature, well-stocked, native, second-growth forests on land conditions similar to those present on the mined sites before they were disturbed.

For all sites (mined and non-mined), a 20x20-meter sample grid was superimposed on the site area using cardinal directions. Attempts were made to place grid lines perpendicular to the banks on open-pit mined sites where more than one spoil bank existed to ensure that the sites' micro-topography was taken into account. A 20 meter buffer strip was maintained around the edge of each forest site. All sampling was performed at grid intersections (Figure 2).

Soil samples were collected from a soil pit dug by hand to 152cm (where possible). Bulk loose samples were collected from each horizon, sieved (2mm) and corrected for coarse fragments for chemical analysis. Bulk density samples were also taken from each horizon and corrected for coarse fragments by subtracting the density of the coarse fragments in each sample. Field data collection took place between May

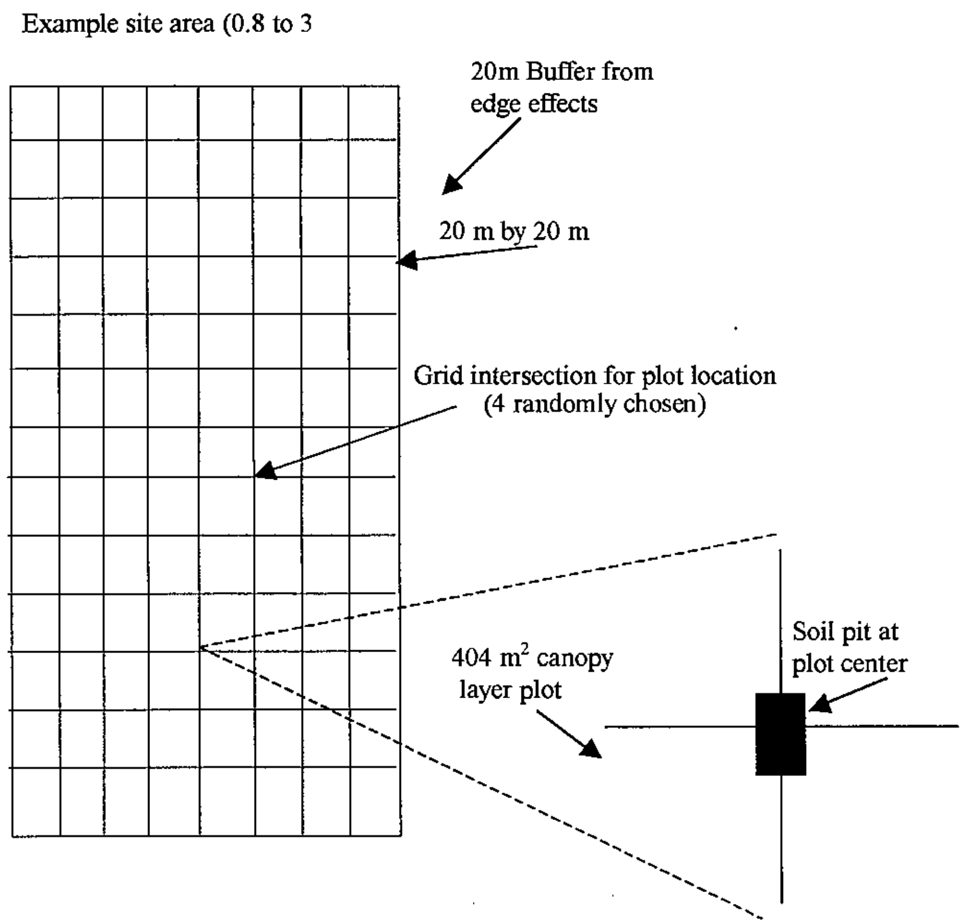

Figure 2: Typical site layout and plot diagram

and August, 1999, with the exception of two sites which were measured in August, 1998.

Site Productivity

Site index (total tree height at a specific base age) was used to estimate site productivity. Site index trees were intermediate shade-tolerant species occupying dominant or co-dominant canopy positions. These trees did not show evidence of stem damage and were in a free to grow position for most of their life. On each of the four measurement plots, tree height and age were measured on one tree of each of the three main species in the canopy layer. Regional site index curves were used in conjunction with tree height and age to obtain estimates of productivity (Carmean et al., 1989). To make direct comparisons between mined sites and their non-mined sites, site index estimates for each species were converted to a site index for white oak (*Quercus alba L.*) using Doolittle's (1958) conversion for species in the Appalachian region. Site index measurements on non-mined sites in each area were identical to measurements on mined sites.

Forest Productivity

Forest productivity was estimated on each site by randomly choosing measurement plots at four grid intersections. Trees in the main canopy ($\geq$13 cm dbh) were tallied within a 404 m^2 circular plot. Merchantable heights were measured to 10 cm tops on trees less than 25 cm at dbh. Trees greater than 25 cm at dbh were measured to a 20 cm top (Figure 2). Tree measurements taken on each site were used to generate regression equations for predicting merchantable tree height and dbh at rotation age. Stands planted with hardwoods were projected to a 60-year rotation age while conifer plantings were projected to a 30-year rotation. Two exceptions included mined sites planted to pine in Indiana (IN-1, IN-2) which were projected to a 60 year rotation due to their older age (50 and 55 years), and two hardwood sites in Kentucky (KY-1, KY-2) that were projected to an age of 30 due to their young stand ages (34 and 35 years). Stand volumes were generated from species-specific volume equations and tables (Smith, 1986; Clark and Saucier, 1990; Clark and Souter, 1996; Ter-Mikaelian and Korzukhin, 1997). MAI measurements for non-mined reference sites were based on the average total tree age across the site and projected to a rotation age of 60. Total tree ages (adjusted dbh age) were obtained in conjunction with site index estimation. Differences in MAI and site index between non-mined and mined study sites were tested using t-tests. Results from statistical tests termed "different" in this paper have a significance level of $p \leq 0.10$.

Results

Site Productivity

Mined site index on midwestern mined sites ranged from 23 m (74 ft) to 28 m (92 ft). Mined sites were 6 % more productive to 12 % less productive than non-mined sites. Overall, site productivity of mined sites was the same as non-mined sites in the midwestern region (Table 1 and Figure 3).

Mined site productivity on eastern mined sites ranged from 17 m (55 ft) to 29 m (94 ft). Mined sites were 16 % more productive to 32 % less productive than non-mined sites. Site productivity on eastern sites was significantly lower on 2 out of 6 mined sites (PA-1, WV-1); other sites were similar in productivity to their non-mined counterparts (Table 1 and Figure 3).

The significant site productivity decline (32%) on mined site WV-1 was due to compaction, shallow rooting depths, and coarse fragments. Average soil depths were 83 cm (33 inches). Trees planted on this site showed a tendency toward surface rooting, suggesting that compaction and excessive amounts of coarse fragments were problems. However, measured bulk densities were low due to the high degree of coarse fragments. High bulk density limits root growth, reduces water infiltration, reduces physical weathering, and lowers available water levels. However, Andrews et al. (1998) found that the excessively rocky nature of young, compacted minesoils soils precluded the use of bulk density as a factor directly affecting white pine growth. In our study, bulk density was important because of the wide variety of soil types encountered. The high coarse fragment content on some sites may have induced water shortages. Poor water retention on mined sites is in part a result of high coarse fragment content, lack of fine earth, and poor soil structural development. These conditions cause lower soil porosities, reduce water retention, and increase doughtiness (Thurman and Sencindiver, 1986). On WV-1, this was further aggravated by the compacted site conditions, which limited root exploitation. This site had the lowest rooting volume (Table 2). Compaction and high coarse fragment content have been identified throughout the eastern region (Daniels and Amos, 1981; Torbert et al., 1994). WV-1 also had one of the lowest base saturation levels of all study sites. Three of the four plots had base saturation levels lower than 45 %, with two plots below 30%.

The mined site in Pennsylvania (PA-1) had problems similar to WV-1. Its site index was 18 % lower than the non-mined site (PA-2), even though the natural site was poorly drained and showed evidence of past farming. PA-1 showed evidence of grading, contained a low average base saturation (48 %), the lowest capillary porosity of all sites, and a high level of coarse fragments (72%) (Table 2).

Forest Productivity

Forest productivity reflects merchantable wood accumulation as a function of all its site and management factors. In the midwestern region, forest productivity (MAI) ranged from 3.4 to 10.7 $m^3ha^{-1}year^{-1}$ (Table 1). Mined sites developed forest productivity levels that ranged from 38% lower to 200% greater than non-mined forests (Figure 3). Forest productivity of mined sites in Illinois and Indiana (IL-1, IL-2 and IN-1, IN-2) was similar to their non-mined counterparts (IL-3, IN-3). In Kentucky, all mined sites (KY-1 through KY-5) were higher in productivity (MAI) than the non-mined site (KY-4).

Forest productivity of eastern mined sites ranged from 3.7 to 12.1 $m^3ha^{-1}year^{-1}$ (Table 1). Mined sites ranged from 26 % less productive to 150 % more productive than non-mined sites (OH-2, WV-2, WV-4, VA-2) (Figure 3). OH-3 was significantly more productive that the non-mined site (OH-2). WV-1 was lower in productivity than its non-mined site, while WV-3 was greater. Other sites in the eastern region were similar in forest productivity to their non-mined counterparts.

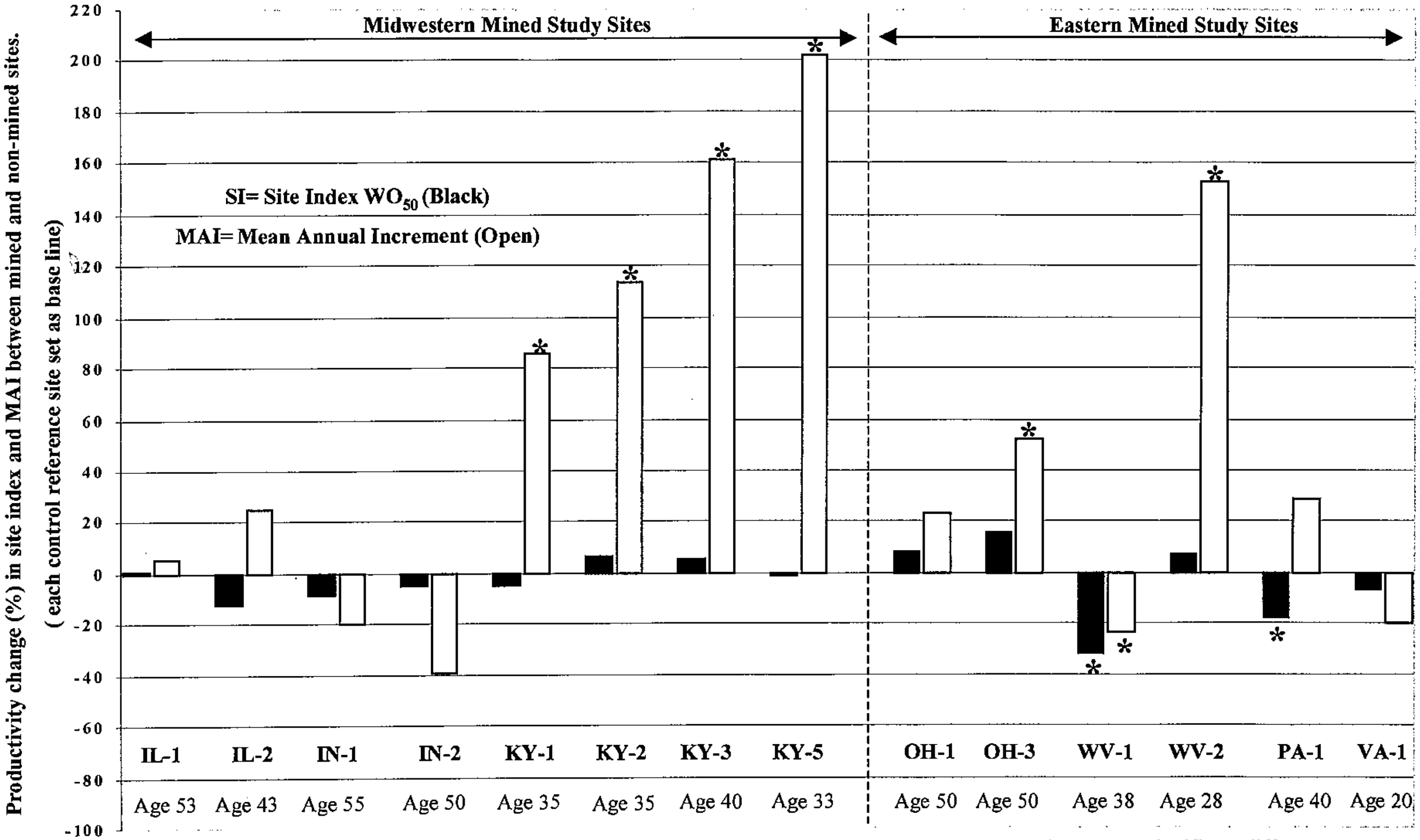

Figure 3: Management impacts on reclaimed mined sites in the midwestern and eastern mining regions. Note: * represent significant differences between mined and non-mined sites at a 0.1 alpha level.

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Discussion

Site Productivity

Pre-SMCRA reclamation on midwestern sites resulted in site productivity levels similar to non-mined forests. Most soil properties were within acceptable ranges for tree growth (Table 2). Some soil properties were not favorable for plant growth, yet others were favorable. Where mining changes one soil property in a negative fashion, other properties may be improved, allowing for productivity levels to remain similar to non-mined sites. McFee et al., (1981) found that mine soil properties varied greatly, making relationships between good or bad properties and tree growth hard to define. For example, mining and reforestation on IL-1 resulted in a better-drained site that contained coarse fragments and ridge/furrow microsite topography. The adjacent control site was a poorly drained bottomland hardwood site containing a water table within 72 cm of the surface when it was measured in late May. IL-1 contained 14 % coarse fragments (by volume) while IL-3 contained only 1 % (Table 2). Poorly drained lowlands are commonly altered during mining and reclamation through the creation of microsite topography and increased coarse fragment content of originally fine textured soils (Sencindiver and Smith, 1978; Pope, 1989). Another example from our study is rooting volumes on mined sites. Increased coarse fragments on mined sites commonly result in lower rooting volumes compared to non-mined sites (Table 2). However, the bulk densities of non-compacted sites may be lower, and spoil depths and nutrient supply from weathering rock may be greater, creating similar productivity levels. Surface mining may increase rooting depth, reduce the effects of natural root limiting layers, and improve drainage and fertility.

Eastern mined sites in Ohio (OH-1, OH-3) had site indices similar to the control site (OH-2). The non-mined site in Ohio showed evidence of being an old-field site having a root-restricting sub-soil horizon. Gullies draining off the control site indicated past agricultural uses may have resulted in severe erosion. Mined site depths in Ohio averaged 150 cm while the non-mined site was limited by bedrock or a root restricting layer within 76 cm. Plass (1982) also found greater rooting depth in mined soils compared to native soils with fragipan or plow pan layers. However, mined sites OH-1 and OH-2 contained much higher coarse fragment contents, which may have reduced the effect of their greater rooting depths. Effects of the coarse fragments can be seen in the comparison of the rooting volumes and subsoil capillary porosities, which are actually similar to or less than the non-mined site (Table 2). Wade et al. (1985) also found contour mine site productivity levels comparable to natural sites in southeastern Kentucky. The authors attributed good mine soil quality to greater soil depth and increased water availability, a result of the mined benches catching downward flow from natural soils above the site. Two of the three contour mined sites measured in this study had greater total depths (VA-2, WV-3). Conversely, eastern sites with degraded productivity levels were compacted and had less exploitable soil volume.

Forest Productivity

The relative difference between the two productivity estimates (MAI and SI) for each site is a result of species differences. Prior to mining, all sites were originally covered with mixed hardwood forests. Conifer species were commonly planted during reclamation, especially in the East, (VA-1, WV-1, WV-3, PA-1, KY-3, KY-5, IN-1, IN-2). The greater forest productivity level of many of these sites reflects the greater growth rates of planted pines (MAI). For pines, culmination of mean annual increment can be reached in 30 to 40 years, while stands of hardwoods take 60 or 70 years to reach maturity. In some cases the use of conifer species masked an apparent reduction in site productivity, or at least reduced its effect (Figure 3, PA-1, WV-1). In other cases, forest productivity levels were much greater than the non-mined sites (KY-3, WV-2), due to appropriate reclamation that allowed expression of the higher growth rates of conifers. Pines can be grown at tighter spacing than hardwoods. The two most productive sites (both pine) also contained the highest stem densities, allowing site resources to be focused on growth of merchantable wood volumes.

High forest productivity was found when fast growing, early-successional hardwood species were planted (KY-1, KY-2). Sites KY-1 and KY-2 contained mixes of cottonwood (*Populus deltoides Bartr. Ex Marsh. Var. deltoides*), sycamore (*Platanus occientalis L.*), and tulip poplar (*Liriodendron tuliperifera L.*). High wood volumes on sites of average quality also occurred on OH-1 and OH-3 due to the planting of early successional hardwoods including tulip poplar, sycamore, ash (*Fraxinus spp.)* and bigtooth aspen (*Populus grandidentata Michx.*). Tulip poplar on IL-1 produced 6.7 $m^3ha^{-1}yr^{-1}$, somewhat lower than its potential due to the presence of planted white oak. Pine and early successional hardwood species are easier to establish, are faster growing, and tolerate less suitable soil conditions than oaks and other mid-successional species.

The planting of certain hardwoods and some conifers may result in a decrease in forest productivity where these species fail to adequately populate the site. Though differences in this case are not significant, they provide an example of the potential of a failed management decision. IN-2, which was planted to pitch pine, had less wood volume and incremental growth than the non-mined site. The pitch pine were unable to establish dominance within 50 years. The pines were planted out of their range and were unable to compete with fast-growing, better-adapted hardwoods. Alkaline soil, present even after 50 years (average pH 7.7, Table 2), may have also contributed to the inability of the pine to establish itself across the site. Other studies show that extremes in pH are detrimental to tree growth (Limstrom, 1960; Deitchman and Lane, 1952). When soil pH approachs 3.0, plants are unable to absorb calcium and phosphorus. At pH 7 and above, micronutrients such as Mn, Zn, Fe, as well as phosphorus, may become deficient (Arnon and Johnson, 1942; Daniels and Zipper, 1997).

Conclusions

Twelve of the fourteen mined sites tested were as productive as their non-mined counterparts. SMCRA requires that land use capability of reclaimed mined sites be comparable to levels that existed prior to mining. Our study shows that trees planted on midwestern reclaimed mined sites prior to passage of SMCRA have the potential to grow as productively as before mining; in the East, mining degraded soil productivity to some degree. The greatest reductions of productivity occurred on compacted sites and on those where chemical and physical spoil properties differed from non-mined soils.

Six out of fourteen mined sites were more productive than their non-mined counterparts, seven mined sites were as productive, and one was less productive. However, fast-growing early-successional species explained high forest productivity on several mined sites. These species may be more tolerant of sites degraded by poor reclamation techniques, and they may provide landowners an option for increasing forest productivity and value on mined land. However, this option does not meet the spirit of SMCRA, as the site quality has not been restored, and even tree species tolerant of poor site conditions will do poorly on sites that have been severely degraded. If proper reclamation is achieved, most species will respond positively.

Productive, mined sites were commonly well-drained, ungraded mixtures of weathered coarse and fine textured materials. Subsurface pHs were acidic but not toxic. Bulk densities were not root-limiting, and capillary porosities ranged from 20 to 30 %. Base saturation was commonly greater than 80 %. The results of this study suggest that site and forest productivity can be restored with current practices that create minesoils consisting of 4 to 5 feet of a weathered mixture of sandstone and shale, that includes the original topsoil and subsoil. Surface soils should be left uncompacted and tree compatible ground covers consisting of a mixture of cool and warm season grasses and low growing legumes should be used for site protection.

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