VOLUNTEER REVEGETATION PROCESSES ON ACID COAL SPOILS IN NORTHWESTERN PENNSYLVANIA[1]

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Abstract.--The vegetation on 20 non-resoiled bituminous strip mines in northwestern Pennsylvania was surveyed to study the factors which account for variability in the quantity and quality of the vegetation. The sites ranged in age from 12 to 41 years. All had acid spoils, and 15 had been planted with trees before abandonment. Two revegetation patterns were discovered. One group of 10 sites had high tree densities (2,333 stem/ha average), high basal area (13.5 m^2/ha average), and were at various stages of forest development. As these sites aged, bare soil disappeared and litter increased. The second group had lower tree densities (1,186 stem/ha average), lower tree growth (2.6 m^2/ha average), and were not developing into forest communities. Instead, the spoils were characterized by patchy vegetation and had large open areas. As these sites aged, bare soil disappeared, but only lichens and mosses increased. The different revegetation patterns were not generally a result of the success or failure of tree-planting efforts. Densities of living planted trees did not differ significantly between the groups. The extent of colonization by volunteer trees, primarily aspens, was the most important determinant of high tree density and eventual forest development. Development of a forest community on the poorly vegetated sites is largely dependent on the recruitment of new trees into open areas. Except for sporadic colonization of grass clumps by red maple, very little recruitment of new trees was occurring. If methods to stimulate colonization of these areas by volunteer trees could be developed, a low-cost reclamation option might be available for thousands of poorly vegetated sites in Appalachia.

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INTRODUCTION

The vegetation of non-resoiled, acidic mine spoils is often quite variable. In northern Appalachia, spoils can develop into dense woodlots within 15-25 years or remain sparsely vegetated or barren for many decades. Although several studies have described the variability of vegetation on unreclaimed, acidic spoils (Croxton 1928, Bramble and Ashley 1955, Byrnes and Miller 1973, Johnson et al. 1982; Gibson and Risser, 1982), few attempts have been made to explain the factors that underlie this variability. Without such understanding, it is unlikely that low-cost reclamation methods can be developed that emphasize natural revegetative processes instead of the expensive, complete reconstruction of sites.

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This paper describes the vegetation of 20 abandoned strip mine sites in northwestern Pennsylvania that vary in age from 12 to 41 years. All were abandoned without any resoiling efforts, and most sites were planted with trees before abandonment. Four sites were limed and fertilized before abandonment. The paper focuses on the general revegetation patterns, the importance of volunteer vegetation (as opposed to planted trees), and factors contributing to the persistence of sparsely vegetated spoils.

STUDY AREA

The study area encompassed 200 m^2 (80 mi^2) in northwestern Pennsylvania (fig. 1). Lower Allegheny Coals (Clarion, Brookville, Lower Kittanning, and Middle Kittanning coals) outcrop throughout the area and have been strip mined by many different operations since the 1930's. Overburdens in the study area are generally characterized by an excess of acid-producing over acid-neutralizing compounds (Williams, et al. 1982). Extensive strip mining in the 1950's and 1960's resulted in thousands of acres of poorly vegetated, extremely acidic spoils and the pollution of most streams in the study area with acid mine drainage. Most of the mining occurred prior to Federal environmental regulation, and State laws in effect during the period only required minimal regrading and planting efforts. All of the sites described in this report were abandoned prior to enactment of resoiling regulations in Pennsylvania in 1973.

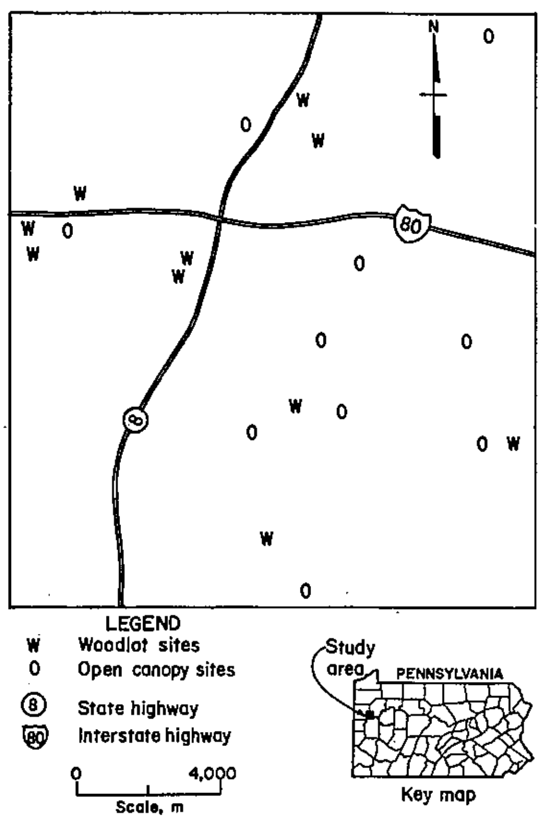

Figure 1.--Location of the study area in Pennsylvania.

METHODS

Initially, all abandoned mine sites in the study area were located, inspected for general reclamation and vegetative characteristics, and aged using Pennsylvania Department of Environmental Resources (DER) permit application records. Sites were sorted into three groups: unaged sites (no permitting records), aged sites without resoiling, and aged sites with resoiling. From a pool of 88 aged, non-resoiled sites, 26 were selected using a stratified random design that maximized the age spread. Sites varied in age from 12 to 41 years. The detailed reclamation history of these 26 sites was determined by reviewing permit files available from the DER in Harrisburg, PA.

The vegetation and soils on each site were sampled at three points. These points were randomly located in flat or gently sloping areas. Because of this topographic constraint, the results presented in this paper may not be applicable to steep spoils with slope instability problems. At each point a 0.02 ha (0.05 a) circular plot was established, and all trees within it were identified and placed into one of four DBH size classes: less than 2.5 cm, 2.5 - 15.0 cm, 15.0 - 18.0 cm, greater than 18.0 cm. Counts within the plots were used to estimate tree stem density. Dead stems were counted, but unless otherwise noted, were not included in density calculations. Basal area was estimated in the field using a basal area gauge (5 BAF). Because this method is inaccurate at low sampling densities for sites with small-diameter trees, basal areas were also estimated from the DBH categories. The correlation between these estimates and field measurements with the basal area gauge was good (r^2 = .94). Results calculated with the second method are reported here because it was considered more accurate on poorly vegetated sites.

In each plot, four 0.5 m^2 ground cover quadrats were established; one centered on the original point and three randomly located. Within each quadrat, cover elements were identified and classified using the Daubenmire cover scale: 0-5%, 5-25%, 25-50%, 50-75%, 75-95%, 95-100% (Mueller-Dombois and Ellenberg 1974). Because cover elements can overlap, this method can result in total cover estimates greater than 100%. The amount of bare soil in each quadrat was also estimated to the nearest 5%.

Soil pH samples were collected from the center of each quadrat by brushing aside any loose ground cover, digging and mixing an area of about 5 cm^2 by about 2.5 cm deep, and collecting approximately 25 cm^3 of soil which was immediately mixed with 50 mL of distilled water. The pH of this solution was measured within 2-3 hours with a Fisher field pH meter.

Upon preliminary review of the field data and permit records, six sites were determined to have been affected by secondary mining or reclamation efforts and were excluded from analytical consideration. Four sites were determined to have been limed and fertilized before abandonment. These sites were not excluded, but the additional reclamation effort was noted during interpretation of the results.

After completion of the survey, additional vegetative and soil pH sampling was done at

Table 1.--Tree stem density on woodlot and open canopy sites.

Site Group	Total den (sx)	Planted[1] den (sx)	Volunteer den (sx)
Open Canopy	1186 (154) a[2]	682 (240) a	777 (131) a
Woodlot	2333 (142) b	856 (252) a	1563 (291) b
Woodlot less two pine plantations	2380 (173) b	554 (188) a	1895 (237) b

den = density in stems/ha.
sx = standard error of mean.

[1]"Planted" calculations are based on six open canopy sites and nine woodlots sites.

[2]Densities with same lower case letter in the same column are not significantly different at 0.05 level.

Table 2.--Tree basal area on woodlot and open canopy sites.

Site Group	Total BA (sx)	Planted BA (sx)	Volunteer BA (sx)
Open Canopy	2.63 (0.83) a	1.45 (0.56) a	1.69 (0.42) a
Woodlot	13.51 (2.43) b	5.34 (2.95) b	8.70 (2.10) b
Woodlot less two pine plantations	12.41 (2.03) b	1.90 (0.65) a	10.75 (2.02) b

BA = basal area in m/ha.
sx = standard error of the mean.

[1]"Planted" calculations are based on six open canopy sites and nine woodlots sites.

[2]Basal areas with same lower case letter in the same column are not significantly different at 0.05 level.

Table 3.--Ground cover on woodlot and open canopy sites.

Site Group	Lichen/Moss mean (%)	Lichen/Moss age corr[1]	Vol Grass mean (%)	Vol Grass age corr	Herbs/shrubs mean (%)	Herbs/shrubs age corr	Litter mean (%)	Litter age corr
Open Canopy	38.3	+.61	25.7	ns	11.2	ns	22.9	ns
Woodlot	25.5	-.67	9.3	ns	43.3	ns	82.5	+.77

"Vol Grass" = volunteer grass.
ns = not significant.

[1]Spearman rank correlation between age and the ground cover component evaluated at the 0.05 level.

site 12. This 12-year-old mine consisted of graded, non-resoiled Middle Kittanning spoil covered by quite heterogeneous vegetation. Approximately one-third of the mine was covered with dense stands of volunteer trees. Volunteer grasses had developed a fairly dense cover (>75%) in some areas, while in others the spoils were completely bare. Numerous pH measurements were made of surface samples collected according to the type and amount of vegetative cover.

RESULTS AND DISCUSSION

Two revegetation patterns were evident on non-resoiled spoils in the study area (Hedin 1987; Hedin and Ehrenfeld, in preparation). Some spoils had high densities of trees and were covered with litter and understory herbs and shrubs where canopies had closed. Other spoils had low densities of trees, and the surfaces were either bare or covered with volunteer grasses, lichens, and mosses.

These patterns were evident on a site level (tables 1, 2, and 3). All sites older than 30 years (n=6) were closed canopy woodlots. Younger sites which had been limed and fertilized before abandonment also had high tree stem densities and were developing into woodlots. All other sites less than 30 years old were characterized by low densities of trees and large areas of sparsely vegetated spoils. Because sites with high densities of trees are on a successional path that results in a closed canopy forest in 25-35 years, they will be referred to as "woodlot" sites. The sites with lower densities of trees and large open areas are not developing directly into a woodlot and will be referred to as "open canopy" sites.

The ground cover differed significantly between woodlot and open canopy sites (table 3). The latter were dominated by lichens (primarily Cladonia) and mosses (primarily Polytrichum), the volunteer grasses broomsedge (Andropogon virginicus) and poverty grass (Danthonia spicata), litter, and bare spoils. On woodlot sites the spoils were generally covered with litter, herbs, and shrubs. For both groups total ground cover increased and bare soil decreased as site age increased. However, the manner in which the ground became covered differed between groups. On open canopy sites only lichens and mosses increased with age (see age correlations in table 3). On the oldest open canopy sites lichens and mosses often formed mats that covered more than 75 pct of the ground-cover quadrats. On the woodlot sites, lichens and mosses decreased with site age, and litter increased. All spoils older than 30 years had a complete litter ground cover.

These different revegetation processes were not generally due to the success or failure of tree planting efforts (tables 1 and 2). Trees had been planted on 9 of 10 woodlot sites and 6 of 10 open canopy sites. Planted trees dominated only two woodlot sites, both of which were dense pine plantations. The survival of planted trees on woodlot sites, judged from current density, was higher but not significantly different than that on open canopy sites. The basal area of planted trees was higher on woodlot sites, largely because of high growth on the two successful sites. When these sites were excluded from the comparison, tree growth of planted trees did not differ between the groups.

Volunteer trees were the most important delineator of the revegetation processes. The density of volunteer trees was significantly higher on woodlot sites than on open canopy sites. Most importantly, on woodlot sites volunteer trees had colonized areas where trees had either not been planted or had died. On open canopy sites, colonization of these open areas was variable and often too sparse to result in closure of the canopy except in isolated groves.

The most important volunteer trees were aspens, Populus grandidentata and P. tremuloides. On woodlot sites aspens dominated the largest size classes of volunteer trees, suggesting that they were the principal colonizers in the first decade following abandonment. On 8 of 10 open canopy sites, aspens represented more than 80% of the volunteer stem density. On these sparsely vegetated spoils, root sprouting had often resulted in small groves of aspens. However, because they remained quite windswept, the spoils beneath were often bare or covered with only lichens and mosses. Aspens were found to be growing and clonally reproducing in very acid soils. On site 12, the pH of surface soils under aspens growing on barren spoils averaged 3.8 (n=53). However, aspens did not appear capable of colonizing open, acidic spoils by seed. Very few seedlings were observed in such areas that could not be associated with a root from a nearby, adult aspen. Aspen's importance thus was due to its original ability to colonize fresh spoils, its tolerance of extremely acidic conditions, and its root sprouting growth form.

Red maple (Acer rubrum) was the second most common volunteer tree. It was observed in old woodlot sites and growing in completely barren spoils on several open canopy sites. On site 12, the pH of surface soils under such maples averaged 3.7 (n=6). This indicated that red maple was capable of growing in extremely acidic soils. Maples were also observed colonizing clumps of volunteer grasses on several poorly vegetated sites. The process was most evident on site 12 (table 4). Numerous red maple seedlings were observed in clumps of grass, even within otherwise barren areas. Although soil pH was significantly higher under grasses than in barren areas, this difference was not the primary facilitating factor. Little colonization occurred in bare soil within the grass-dominated areas, despite higher pH. The more important role of grass clumps was probably to trap blowing seeds and provide a moist microenvironment for germination and inital seedling development.

Table 4.--Relationship between ground cover, density of red maple seedlings, and soil pH on a 12-year-old site

Ground Cover	area sampled (m2)	Seedling Density (stems/m^2)	soil pH
Bare Soil	377.1	0.01	3.54
Clumps of Grass in Barren Areas	15.4	4.03	3.70
Grass Area: Clumps	17.0	6.47	3.93
Grass Area: Bare soil	11.3	0.17	3.85

This recruitment process was quite spoil-specific. It was important in areas where grasses were a dominant cover component and where red maple seed sources were numerous. These conditions were only satisfied at two sites: the 12- and 15-year-old sites. Poorly vegetated spoils on the other sites were usually missing one or both of these conditions, and recruitment of maples was less common and sporadic.

Black cherry (Prunus serotina) was observed in the canopies of some woodlots and also growing on open canopy sites, but like red maple, the densities were quite variable. The high densities of black cherry that were observed on two woodlot sites appeared to be associated with dead black locust plantings. In four areas where the density of dead locust stems averaged 445/ha, black cherry averaged 1,050 stems/ha, and many of these were canopy-sized. In two areas on the same sites where no dead or alive black locust were observed, black cherry only averaged 124 stems/ha. (These latter areas had aspen canopies.) A similar facilitative relationship between black locust and recruitment by black cherry has been found for Ohio spoils (Larson 1984).

LONG-TERM SUCCESSIONAL CHANGES ON OPEN CANOPY SITES

Eventually, even the open canopy sites are expected to develop into woodlots. The number of decades required for this succession is dependent on the size of open areas and the rate at which they are revegetated by clonal expansion of existing trees and colonization by new trees. Rates of expansion of aspen clones on acid spoils have never been reported, however, on alkaline iron ore spoils in Minnesota, Leisman (1955) found that quaking aspen expanded by 3.3 m/decade. This rate does not account for the additional 10-20 years required for young root sprouts to reach mature size. On sites characterized by unvegetated areas less than 10 m across and high densities of aspen, this process is capable of causing woodlot development after several decades of clonal expansion. Several open canopy sites in the study area fall into this category. However, thousands of sites in northern Appalachia contain much larger open areas and/or low densities of clonally reproducing trees. On such sites, development of a woodlot condition is primarily dependent on colonization of new trees into open areas. This process is logically related to the amelioration of conditions that currently limit colonization.

Several chemical and physical factors combine to limit growth on bare acidic spoils. The pH of completely bare soils in the study area was typically less than 4.0 and on site 12 was 3.54 (n=94). This pH level is toxic to most plants (Arnon and Johnson 1942, Coleman and Thomas 1967) and few seeds germinate under such acid conditions. Extremely acidic spoils also typically have high exchangeable aluminum levels which cause shallow and irregular root development (Berg and Vogel 1973). Seedlings with root deformations are quite vulnerable to extremes in soil moisture and temperature that are common on unshaded spoils (Deely and Borden 1973, Bell and Ungar 1982). Although these conditions are too harsh for colonization and establishment by most seeds, they are suitable for growth by many plants with established root systems (Bell and Ungar 1982).

Over time, the extreme chemistry of bare spoils ameliorates, and they are invaded by vegetation. In the study area, both soil pH and exchangeable aluminum were strongly related to spoil age (Hedin 1987). The most important invaders of bare acid spoils in northern Appalachia are grasses, lichens, and mosses (Bramble and Ashley 1955, Bell and Ungar 1982, Huey 1973). Because these plants cover or shade the spoils and provide important inputs of soil organic matter, one might expect that colonization by trees would soon follow. In the study area, only grasses show such facilitative tendencies, and the effect is quite spoil-specific. Only those open areas with both coverage of grass and large numbers of nearby seed sources were observed to have high recruitment of volunteer trees.

The most common cover of open areas in the study area was by lichens and mosses. On the oldest sites, extensive mats were common. Although no temperature or moisture measurements were made, it is reasonable to expect significant moderation of soil temperature and moisture extremes in these areas. Soils under these mats were also less acidic than in bare areas. The average pH of soils in quadrats with lichen and moss covers greater than 50% was 4.37 (n=41) compared to an average pH of 3.80 for quadrats with greater than 50% bare soil. Numerous tree seedlings were observed on woodlot soils with similar pH, but very few tree seedlings were observed in areas dominated by lichen and mosses. The cause of this low colonization may be biochemical. Chemicals produced by the dominant lichen, Cladonia, have been shown to reduce tree seed germination (Brown, 1967) and also to inhibit growth of mycorrhizae fungi that are important symbionts of successful woody colonizers on acid spoils (Goldner et al. 1986).

It thus seems that, although established trees are quite capable of growing on bare acidic spoils, initial establishment is quite difficult. Depending on the ground cover that invades the spoils in the first three decades of abandonment, this colonization problem may disappear or persist. When open areas are small and aspens are abundant, clonal expansion can fill in voids and result in development of a woodlot in 40-75 years. When open areas are larger, but become vegetated with grasses that facilitate secondary colonization by maples, woodlot development in a similar timeframe appears possible. However, where open areas are large and a cover dominated by lichens and mosses develops, minimal recruitment of new trees occurs in the first 30 years of abandonment. How long the colonization deterrence will persist is unknown, but it seems assured that the patchy, sparse vegetative conditions will persist, at the minimum, for 50-100 years after original abandonment.

RECLAMATION POSSIBILITIES

The revegetation options for these sites and similar ones throughout Appalachia range from complete reconstruction to complete neglect. Those sites with dangerous highwalls or pits require regrading efforts which will necessarily destroy the current soils and vegetative communities. However, thousands of spoils do not have features that require regrading work and are thus amenable to alternative, less costly revegetation strategies. In areas where woodlots are consistent with surrounding land uses and have aesthetic, forestry, or wildlife value, revegetation to a forested condition should be considered. One method of attaining this condition that has not been considered is the stimulation and acceleration of natural reforestation processes.

This strategy requires that the factors preventing colonization of sparsely vegetated spoils be identified, and methods be developed that would remove the limitations for several growing seasons. In northern Appalachia such research efforts should focus on aspen trees because they are capable of densely colonizing spoils, they grow quickly (Perala and Carpenter 1985), they can fill in small uncolonized areas by root sprouting, they facilitate the colonization of more valuable tree species, and their seeds are readily available every spring.

Indirect evidence exists that liming and fertilization can stimulate colonization of aspen trees on acidic spoils. One of the sites originally included in this survey was eliminated from analytical consideration because the current landowner had limed and seeded portions of the spoils with grasses and legumes 10 years ago. The spoils have reacidified and most of the grasses and legumes have since disappeared, however, the spoils are now densely covered with young aspen saplings, most of which are not root sprouts. A similar cohort of young aspens was not observed on unamended portions of the site (Hedin 1987). During the construction of Moraine State Park in western Pennsylvania, acid spoils were limed and planted with a variety of tree seedlings. Most of the planted trees died (Medve 1973); however, the spoils were densely colonized by volunteer trees, primarily aspens (Medve 1974). If a method for determining the proper mixture of limestone and fertilizer necessary to stimulate colonization of poorly vegetated sites could be developed, local groups would have a low-cost reclamation option that would dramatically change the vegetation and landscapes of many extensively strip mined areas.

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