Land Reclamation

Survival of Three Tree Species on Old Reclaimed Surface Mines in Ohio

J. D. Zeleznik and J. G. Skousen*

ABSTRACT

Early studies of mine reclamation emphasized trees for revegetating minesoils. Scientists of the USDA Forest Service transplanted four tree species in 1946 into leveled or unleveled overburden near Georgetown, OH, and into unleveled overburden near Dundee, OH. Black locust (*Robinia pseudoacacia* L.) had good initial survival on both sites but died in later years due to locust borers (*Megacyllene robiniae*). Survival and growth of remaining white ash (*Fraxinus americana* L.), white pine (*Pinus strobus* L.), and yellow-poplar (*Liriodendron tulipifera* L.) were determined and soil properties examined on both sites in 1992. Minesoil bulk density in Georgetown leveled areas was similar (1.1 to 1.2 Mg/m^3) to unleveled areas in 1992. Minesoil pH was 7.7 and no nutrient deficiencies were found. Bulk density at Dundee was 1.1 Mg/m^3 and minesoil pH was 4.2 with high exchangeable acidity, Al, and Fe concentrations. White ash had the best survival after 46 yr, averaging 43% in both leveling treatments at Georgetown and 33% at Dundee. White pine survival averaged 22% at Georgetown and 14% at Dundee. Yellow-poplar had poor survival (3%) on Georgetown leveled areas, 21% survival on Georgetown unleveled areas, and 17% survival at Dundee. White pine and yellow-poplar trees were 4 to 6 m shorter on Georgetown leveled areas vs. unleveled areas. White ash height was similar between leveling treatments and no height differences were seen for any species between Georgetown unleveled and Dundee. Volume for yellow-poplar ranged from 39 m^3/ha on the Georgetown leveled area to 350 m^3/ha on unleveled areas. Volumes roughly paralleled survival for white pine and yellow-poplar. Thirteen volunteer tree species were identified and they averaged 20% total tree basal area across the three areas. Maple (*Acer* sp.) and elm (*Ulmus* sp.) were two common volunteer trees. After 46 yr, these areas support a closed canopy of commercially valuable trees, providing soil stabilization, potential economic returns, and wildlife habitat. Eastern U.S. surface mine reclamation should emphasize tree planting and forests as postmining land uses. White ash is recommended on leveled or unleveled sites with alkaline or acidic minesoils.

COAL MINING has disturbed approximately 2.4 million ha (6 million acres) since 1930 in the USA. The majority of land mined for coal was originally forested in Appalachia where much of the surface coal mining had occurred in the USA prior to 1975. 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 some reclamation would take place. Reclamation prescribed in these early laws directed soil, subsoil, and overburden (the geologic material overlying the coal) be used to refill excavated areas. Backfilling and leveling the land was specified with subsequent planting of trees and shrubs in regraded areas.

Studies of surface mine revegetation with trees began in the 1920s and reports on planting success began in the 1940s. Black locust was the most extensively studied and successful species (Brown and Tryon, 1960; Chapman, 1944, 1947; Potter et al., 1955). Other species such as Virginia pine (*Pinus virginiana* Mill.), red pine (*P. resinosa* Ait.), and white pine also grew well in many of the early studies (Brown, 1962; Minckler, 1941). Hardwoods like oaks (*Quercus* sp.) and cherry (*Prunus*

J.D. Zeleznik, Dep. of Forestry, Michigan State Univ., East Lansing, MI 48824-1222; and J.G. Skousen, Div. of Plant and Soil Sciences, West Virginia Univ., Morgantown, WV 26506-6108. Scientific Article no. 2534 from the West Virginia Agric. and For. Exp. Stn., Morgantown. This research was supported by funds appropriated under the Hatch Act. Received 4 Jan. 1996. *Corresponding author (jskousen@wvn.edu).

Published in J. Environ. Qual. 25:1429–1435 (1996).

sp.) failed to grow usually because the trees sustained rodent damage (Brown, 1962).

Laws and regulations during ensuing decades prescribed seeding grasses and legumes rather than establishing trees for surface mine reclamation in the eastern USA (Torbert and Burger, 1996). The rationale for this change from tree planting was that forage species controlled erosion and provided a quick economic return to land owners through haying or grazing of livestock. Mined areas revegetated with grasses and legumes under management produced sufficient quantities of forage. Unmanaged areas, however, declined in forage production and generally were invaded by undesirable weedy species and, to a lesser extent, adjacent tree species (Torbert et al., 1988). Establishment of a forest with commercial value is extremely slow by natural succession.

Forests have a number of advantages as a postmining land use (Faulconer et al., 1996). First, long-term stabilization of the site is accomplished even though during initial stages some erosion may occur. Second, establishment of desirable tree species capable of maintaining the site will slow or prohibit invasion of less desirable, weedy species. Third, trees will eventually provide economic returns although several decades must generally pass before harvesting. Fourth, tree planting aids in developing wildlife habitat and promotes hydrologic balance in the watershed.

Many studies were established in the 1940s and 1950s to evaluate tree species and tree planting techniques for reclaiming mined sites. Tree survival, however, was usually only reported 2 yr, 5 yr, or 10 yr after establishment (Finn, 1958). Successful initial survival does not always translate into successful long-term site stabilization and development of a forest with commercial value (Zisa et al., 1980). Re-evaluating tree plantings after many years will aid in prescribing which tree species have long-term survival, show suitable growth and timber production potential, and contribute to the site's overall health in terms of economics, aesthetics, and the environment.

This study evaluates survival and growth of three transplanted tree species at two 46-yr-old surface mines in Ohio. Comparisons were made between: (i) leveled and unleveled areas and (ii) between unleveled acidic and unleveled alkaline overburdens. Soil properties were measured and related to survival and growth of these tree species.

METHODS

Study Areas

Researchers at the USDA Forest Service, Central States Forest Experiment Station (CSFES) established experimental plantations on a number of surface mines in eastern and southeastern Ohio in 1946 to 1947. This 1992 study re-evaluated the Georgetown site (located in Harrison County, Ohio) and the Dundee site (located in Tuscarawas County and Holmes County, Ohio). The Georgetown site was mined in 1943 to 1944 for the No. 8 (Pittsburgh) coal bed and the Dundee site was mined for the No. 5 (Lower Kittanning) coal bed in 1941 to 1942. Stratigraphic descriptions of each overburden are shown in Table 1 (G.A. Limstrom, 1946, unpublished reports). During surface mining, overburden was blasted and moved by mechanical shovels into an adjacent area, followed by coal extraction. Subsequent mining cuts removed overburden and placed it back into mined cuts where coal had been removed. This process continued resulting in a land surface consisting of a series of ridges and troughs. Some of the area at Georgetown was leveled and some was not. The resulting minesoils on Georgetown are classified as Morristown channery silty clay loam (loamy-skeletal, mixed (calcareous), mesic Typic Udorthent; USDA, Soil Conservation Service, unpublished data, Cadiz, OH). No leveling occurred at Dundee and the minesoils are classified as Bethesda channery clay loam (loamy-skeletal, mixed, acid, mesic Typic Udorthent) (Waters and Roth, 1986).

The Georgetown study was initially established to investigate the effects of minesoil leveling on survival and growth of four species: black locust, yellow-poplar, white pine, and white ash. Leveled areas were created by small bulldozers and gently sloped (average of 8% slope) to allow surface runoff (G.A. Limstrom, 1946, unpublished reports). Unleveled areas had slopes ranging from 10 to 30% on short ridge sides. The original study at Dundee compared tree species, age class of planting stock, and tree species planted in mixtures.

Field Plots

Areas of 1.2 ha were originally selected on each leveling treatment at Georgetown and on an unleveled area at Dundee. Twelve plots, each 1024 m^2, were established in each of these areas and plots were randomly assigned one of four tree species with three replications. Seedling spacing was 2.1 × 2.1 m for a stocking of 2220 trees/ha. For our measurements, a small plot of 200 m^2 (14 × 14 m) was established randomly in one of the corners within each 1024 m^2 plot in the summer of 1992. Only plots planted to white pine, white ash, and yellow-poplar were evaluated. Black locust had very good initial survival but was decimated by the locust borer in later years (Larson and Vimmerstedt, 1983). Several parts of white ash

Table 1. Stratigraphic descriptions of overburden at Georgetown and Dundee (G.A. Linstrom, 1946, unpublished reports).

Overburden layer	Thickness	Depth
	—— m ——	
Georgetown		
Soil, acidic, brown, silty clay loam, single-grained	0.3	0.3
Clay, partly shaly, acidic, brown, blocky structure	0.9	1.2
Shale, acidic, gray-brown, clayey	4.6	5.8
Shale, alkaline, carbonaceous, clayey	0.3	6.1
Limestone, reddish-yellow, massive	8.2	14.3
Shale, acidic, gray, hard, clayey, greasy	0.9	15.2
Coal, Redstone	0.3	15.5
Limestone, reddish-gray, massive	6.1	21.6
Shale, alkaline, gray, mixed with limestone	1.8	23.4
Coal, No. 8, Pittsburgh		
Dundee		
Soil, acidic, brown, loam, single-grained	0.2	0.2
Sand, acidic, reddish-yellow, intermixed with sandstone fragments	1.5	1.7
Sandstone, acidic, reddish-yellow, fragmental, ferruginous	3.4	5.1
Shale, carbonaceous, grayish-black, mottled red, thin-bedded	7.9	13.0
Shale, carbonaceous, grayish-black with red mottling, ferruginous	3.4	16.4
Coal, No. 5, Lower Kittanning		

Abbreviations: CSFES, Central States Forest Experiment Station; dbh, diameter at breast height; CEC, cation-exchange capacity; LSD, least significant difference;

and yellow-poplar plots in the leveled area at Georgetown were lost to a power line right-of-way and some parts of other plots were missing. Randomly chosen sampling plots occurring in cleared areas were moved to undisturbed areas of the plot.

Tree Sampling and Analysis

Each tree in 200 m^2 plots was identified as planted or volunteer. Tree survival was calculated by the number of planted species found in the sampling plot divided by 45 trees originally planted. Diameter at breast height (dbh) was measured on all trees ≥7.6 cm dbh (including volunteers) and these values were used to calculate basal area. The height of each fifth planted tree was measured using an Abney level. Volume (m^3/ha) was determined as: [0.5 × average basal area (m^2) × average height (m)] × trees per ha.

Soil Sampling and Analysis

Ten soil samples were taken in a grid pattern from each 200 m^2 plot to a depth of 15 cm. The first five samples were combined into one composite and the last five were combined into a second composite. Each composite soil sample was tested for >2 mm rock fragment content by passing it through a sieve. All rocks not passing the sieve were placed in a bucket, weighed, and discarded. Rock fragment percent was calculated from the weight of rocks divided by the weight of rocks and soil material. A representative <2 mm soil sample was placed in a plastic bag for laboratory analysis. Surface soil cores (7.6 cm diameter and 7.6 cm depth) also were taken at five equally-spaced locations within each plot for total bulk density determination including rocks (Sobek et al., 1978).

Soil texture was determined on <2 mm material by pipette (Sobek et al., 1978). Soil pH was measured with a Fisher Scientific Accumet pH meter on a 1:1 soil/water paste (Sobek et al., 1978). Exchangeable acidity was determined by 1 *M* KCl extraction followed by NaOH titration to pH 8.2 using a Fisher Scientific computer-aided titrimeter (Soil Survey Staff, 1984). Exchangeable bases (Ca, Mg, K, and Na) were extracted by 1 *M* ammonium acetate at pH 7.0 (Soil Survey Staff, 1984). Cation-exchange capacity (CEC) was determined by summing exchangeable bases (converted to $cmol_c$/kg) plus exchangeable acidity. Copper, Fe, Mn, and Zn were measured by DTPA extraction (Lindsay and Norvell, 1978). Organic C was determined by acid dichromate digestion with $FeSO_4$ titration (Soil Survey Staff, 1984). The results of the two soil composites for each species plot (three species plots per area) were averaged to give one value for each area and standard errors for the means were calculated.

Data Analysis

Tree variables of interest were: (i) survival, (ii) height, and (iii) volume per ha. A one-way ANOVA was used to compare mean values among species and for species × leveling treatment interactions between Georgetown leveled and unleveled areas, and mean values among species and for species × site interactions between Georgetown unleveled areas and Dundee unleveled areas. When significant differences were found, means were separated using the least significant difference (LSD) test (Dowdy and Wearden, 1991). To help stabilize the variance for survival, the data were transformed using the square root of the arcsine as the dependent variable for statistical analysis.

RESULTS

Soils

Soil textures at Georgetown were silty clay loams (>85% silt and clay) in both leveled and unleveled plots (Table 2) reflecting the high amount of shale and limestone in the overburden (Table 1). Rock fragments at the time of plantation establishment in 1946 on Georgetown accounted for 43% of the minesoil total weight (G.A. Limstrom, 1946, unpublished reports). This same value was found for Georgetown unleveled minesoils in 1992 and the leveled area was substantially lower at 32% rock fragments. More rock fragments may have simply been due to more erosion of fine earth material from unleveled areas before trees stabilized the steep ridges and side slopes. Both unleveled and leveled minesoils had more rock fragments than most of the adjacent undisturbed soils: 10 to 20% rock fragments for Coshocton, Guernsey, and Westmoreland series (Waters and Roth, 1986). Another soil series in the area (Hazelton) had rock fragment contents similar to leveled minesoils.

Dundee soil had 19% sand, 46% silt, and 35% clay in 1992 (Table 2) showing the predominance of shale overburden (Table 1). Limstrom and Merz (1949) reported sand percentage to be 27% and silt to be 35% on this site. Rock fragment content at Dundee was 66% in 1949 as compared with 41% in 1992. Apparently, the shale fragments weathered over time resulting in an increase in silt.

Bulk densities of Georgetown and Dundee minesoils were between 1.1 to 1.2 Mg/m^3, well within the range reported (1.0 to 1.3 Mg/m^3) for native undisturbed forests in the eastern USA (Brady, 1990). We suspected that surface leveling with small bulldozers may have originally compacted the soils resulting in higher bulk densities on leveled plots. Either there was no original soil compaction or it was nullified after 46 yr by freeze and thaw cycles, root penetration, organic matter additions, and soil organisms, all of which could have reduced bulk density. While old minesoils are nearly equal in bulk density to natural soils (Schafer et al., 1979), new minesoils are compacted producing higher bulk densities (Torbert and Burger, 1990, 1996). Soil compaction causes low aeration, less water infiltration, more runoff, and high physical impedance to root growth (Hatchell et al., 1970). Bulk densities that severely restrict or stop root growth range from 1.5 to 1.8 Mg/m^3 (Forristall and Gessel, 1955; Heilman, 1981, 1990; Minore et al., 1969; Simmons and Pope, 1987, 1988) depending on tree species and soil texture. Hatchell et al. (1970) estimate that 18 yr were required for bulk density on log decks to return to that of undisturbed soils. Perry (1964) estimates it takes about 40 yr for recovery of infiltration in an old woods road.

Organic C was 2.8% in Georgetown leveled vs. 1.9% in unleveled minesoils, and 2.4% on the acidic Dundee site (Table 2). The difference between leveled and unleveled minesoils on Georgetown also may be due to erosion and movement of leaf litter and organic matter downslope.

Minesoil pH was >7.5 on Georgetown due to high

Table 2. Mean values and standard errors (in parenthesis) of soil parameters at Georgetown by leveling treatment, and at Dundee.

Parameter	Unit	Georgetown Leveled area	Georgetown Unleveled area	Dundee unleveled area
Sand	%	12.6 (0.7)	11.7 (0.4)	18.8 (1.3)
Silt	%	53.4 (0.9)	56.4 (0.3)	46.3 (0.6)
Clay	%	34.1 (1.2)	32.0 (0.3)	34.9 (1.6)
Rock fragments	%	32.4 (0.05)	42.9 (0.04)	41.3 (0.04)
Total bulk density	Mg/m^3	1.13 (0.01)	1.22 (0.03)	1.07 (0.03)
Organic C	%	2.79 (0.05)	1.86 (0.09)	2.38 (0.11)
Cation-exchange capacity	$cmol_c/kg$	18.9 (0.3)	15.8 (0.4)	15.8 (0.5)
pH	s.u.	7.63	7.70	4.15
Exchangeable acidity	$cmol_c/kg$	0 (0)	0 (0)	5.1 (0.3)
Calcium	mg/kg	450 (7.2)	431 (6.2)	36.3 (2.9)
Potassium	mg/kg	4.71 (0.19)	4.80 (0.12)	2.92 (0.1)
Sodium	mg/kg	0.66 (0.05)	0.53 (0.04)	0.60 (0.04)
Magnesium	mg/kg	32.8 (2.2)	35.3 (1.7)	16.4 (1.6)
Sulfur	%	0.12 (0.01)	0.25 (0.07)	0.21 (0.02)
Aluminum	mg/kg	0.07 (0.04)	0.17 (0.07)	377 (42.5)
Copper	mg/kg	2.00 (0.06)	1.71 (0.08)	2.20 (0.15)
Iron	mg/kg	29.1 (1.8)	32.9 (1.5)	269 (17.2)
Manganese	mg/kg	12.1 (0.5)	9.2 (0.9)	30.0 (2.3)
Zinc	mg/kg	3.50 (0.12)	3.35 (0.16)	3.30 (0.21)

amounts of limestone and calcareous shale in overburden, and exchangeable cations were at suitable levels for plant uptake and nutrition (Table 2). Soil pH was 4.2 on Dundee and exchangeable acidity was 5 $cmol_c/kg$. Aluminum and Fe were both high at Dundee compared with Georgetown and exchangeable cations were lower. Trees generally grow better in soils where pH is 5.5 or less (Skousen et al., 1994), and this is especially true for white pine.

Tree Survival and Growth

White ash had the highest survival (33 to 46%) on all areas after 46 yr (Table 3). Yellow-poplar had poor survival on Georgetown leveled areas (3.3%) and better survival at Dundee (17%) and Georgetown unleveled areas (21%). White pine survival was 14% on the acid Dundee site, 18.5% on the Georgetown unleveled area, and 25% on the Georgetown leveled area. White pine was expected to have higher survival in an acid soil like Dundee compared with the alkaline Georgetown soils. This was not the case. The only species significantly different was yellow-poplar. Survival values were similar for these species as reported by Larson and Vimmerstedt (1983) across several planted sites in Ohio. Minckler (1941), studying old-field plantations in Appalachia, found yellow-poplar and white pine survived very poorly on steep slopes while white ash survived much better. Leveling the site has shown mixed results on seedling survival depending on species and site (Brown, 1962; Czapowskyj and McQuilkin, 1966; Sawyer, 1949; Torbert and Burger, 1990).

Table 3. Survival (%), height (m), and volume (m^3/ha) of three tree species transplanted in leveled and unleveled minesoils at Georgetown and in unleveled minesoils at Dundee. Statistical comparisons (ANOVA) were made between Georgetown leveled and unleveled areas, and between Georgetown unleveled and Dundee.

Area / Tree species	Survival	Height	Volume
	%	m	m^3/ha
Georgetown leveled			
White ash	45.6a†	18.6ab	347a
Yellow-poplar	3.3d	14.8b	39b
White pine	25.2ab	16.7b	198ab
Average	24.7	16.7	195
Georgetown unleveled			
White ash	40.0ab	18.5ab	274a
Yellow-poplar	20.7bc	22.2a	350a
White pine	18.5c	21.7a	229ab
Average	26.4	20.8	284
Dundee			
White ash	32.6‡	17.0	189
Yellow-poplar	17.0	17.2	246
White pine	14.0	20.8	197
Average	21.2	18.3	211

† Means within a column for Georgetown leveled and unleveled only followed by the same letter are not significantly different at $P \leq 0.05$.

‡ ANOVA found a significant difference in survival among species between Dundee and Georgetown unleveled areas at $P \leq 0.01$. The LSD test indicated that white ash survival was significantly higher than the other species. There were no other species effects or species/site interactions between Georgetown unleveled and Dundee.

White ash grew equally well on Georgetown leveled and unleveled areas (Table 3). Height was significantly lower on Georgetown leveled areas for both yellow-poplar and white pine compared to unleveled areas. Many workers have shown that soil compaction reduces height growth of trees (Finn, 1958; Foil and Ralston, 1967; Halverson and Zisa, 1982; Hatchell et al., 1970; Torbert and Burger, 1990, 1996; Youngberg, 1959). Trees on unleveled areas grow as well and sometimes better than those on nearby undisturbed soils (Czapowskyj and McQuilkin, 1966; Heilman, 1990; Tryon, 1952). Tree height was not significantly different on Georgetown unleveled vs. Dundee unleveled areas.

The results for volume roughly paralleled those of height (Table 3). The white pine average of 208 m^3/ha on Georgetown and Dundee compares well with Schuster and Hutnik's (1983) average of 195 m^3/ha on a 35-yr-old reclaimed site in Pennsylvania. Our results were within 10% of those predicted for white pine at similar levels of stocking, age, and site index (Dale et al., 1989; Leak et al., 1970). Low volume was closely related to low survival for yellow-poplar in Georgetown leveled areas.

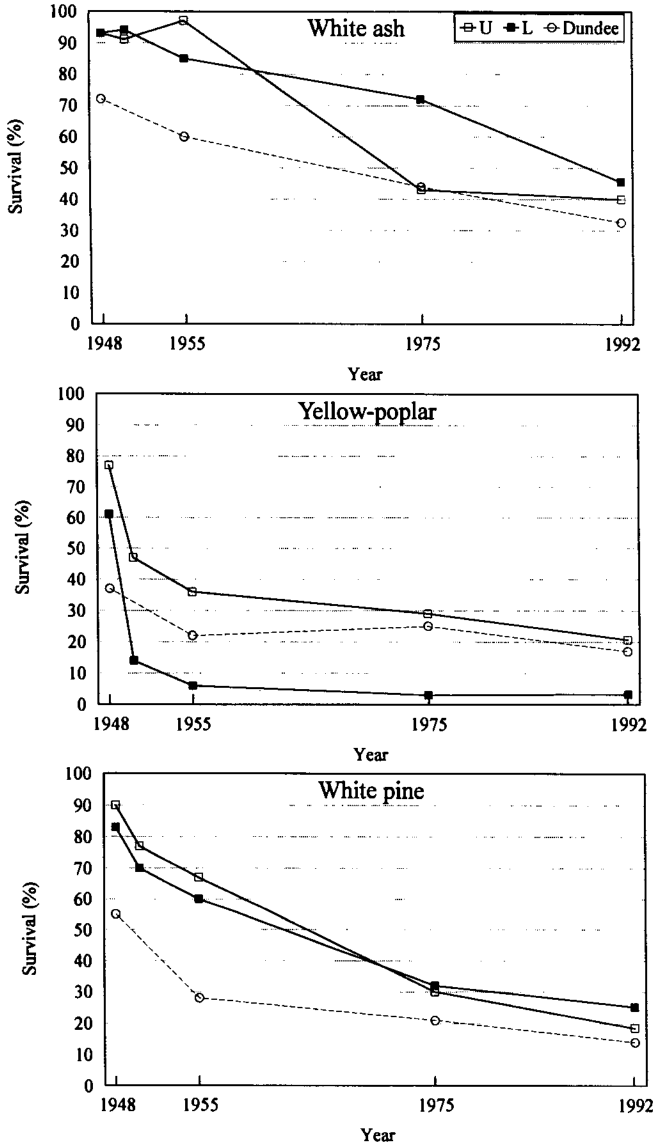

Fig. 1. Survival of planted trees on Georgetown leveled (L) and unleveled (U) minesoils and Dundee unleveled minesoils from 1948 to 1992. (Data prior to 1992 courtesy of Dr. Jack Vimmerstedt, Ohio Agric. Res. and Devel. Ctr., Wooster, OH.)

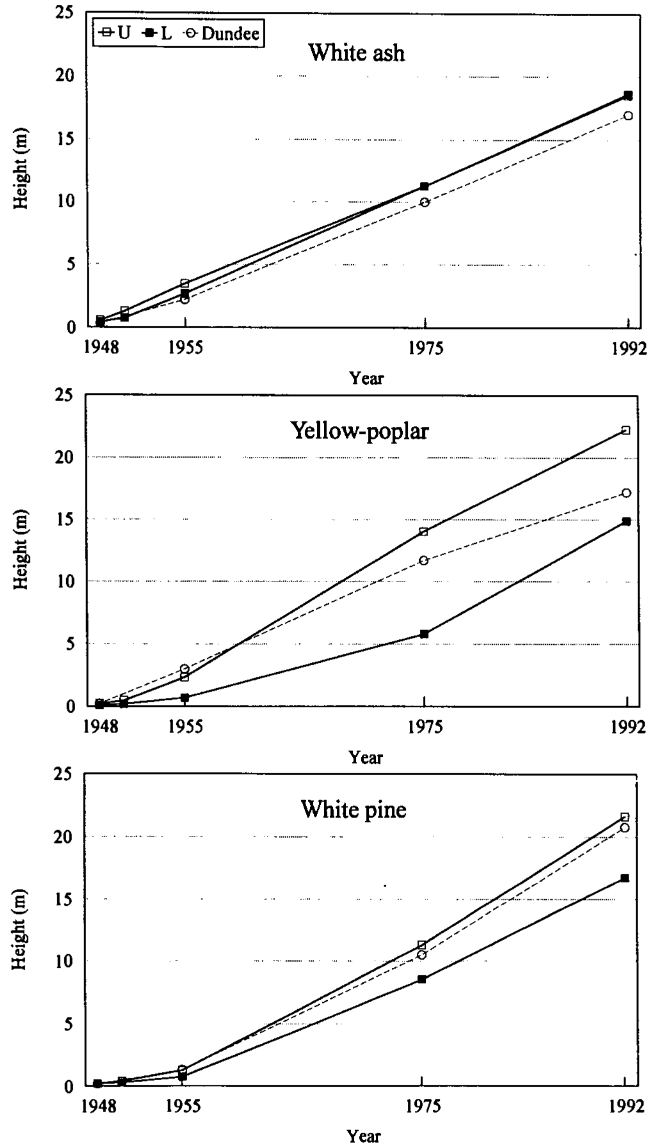

Fig. 2. Height of planted trees on Georgetown leveled (L) and unleveled (U) minesoils and Dundee unleveled minesoils from 1948 to 1992. (Data prior to 1992 courtesy of Dr. Jack Vimmerstedt, Ohio Agric. Res. and Devel. Ctr., Wooster, OH.)

Using data from the U.S. Forest Service in 1948, 1950 (Georgetown only), 1955, 1975, and our data in 1992, white ash survival at Georgetown dropped gradually from 93% in 1948 to around 45% in 1992 (Fig. 1). White ash on unleveled areas particularly declined between 1955 and 1975. Dundee white ash survival was 72% in 1948 and decreased to 33% survival after 46 yr. Survival was especially poor during the period between planting (1948) and 7 yr later for yellow poplar and white pine. Early height growth of white ash did not appear to be affected by leveling treatment because the slopes of the lines appear very similar, nor did the acid minesoil have an influence on white ash growth (Fig. 2). Yellow-poplar growth on Georgetown leveled areas appeared to be slower than that of unleveled areas. Height growth of trees on unleveled areas at Dundee and Georgetown were similar.

Volunteer Trees

A summary of the volunteer trees species, number of stems, and percentage of total basal area due to volunteer trees is found in Table 4. Only three of the 13 volunteer tree species were found in six or more of the possible nine planted plots. Elm (*Ulmus* sp.) was found in all three areas (both Georgetown areas and Dundee) and within plots of every planted species except for Georgetown leveled white ash. Black cherry (*Prunus serotina* Ehrh.) and unplanted white ash and white pine were also found on at least one plot in each area. White pine volunteers were only found in plots where it had been planted. The least common volunteers were dogwood (*Cornus florida* L.) and chokecherry (*Prunus pensylvanica* L.). White ash plots had the fewest volunteers in terms of number of stems because of its high survival rate. Greater than 30% of the total basal area due to

Table 4. Number of stems ≥7.6 cm dbh (#) and percent of total basal area (BA) of volunteer trees in each planted species plot on Georgetown leveled and unleveled minesoils, and Dundee minesoils. Totals for volunteer trees include number of stems ≥7.6 cm dbh (#), the percentage of volunteer stems to total stems (% of total stems), percent of total basal area due to all volunteer trees (BA), and number of volunteer tree species (# of species).

		Georgetown									
		Leveled area			Unleveled area			Dundee unleveled			
Tree species		WA†	YP	WP	WA	YP	WP	WA	YP	WP	Total
Maple	(#)	–	–	–	–	–	1	9	7	7	24
	(BA)	–	–	–	–	–	0.3	4.6	5.2	12.4	22.5
Elm	(#)	–	4	2	1	1	1	2	2	3	16
	(BA)	–	35.3	1.9	0.4	0.8	0.3	2.7	1.1	4.2	46.7
White pine	(#)	–	–	5	–	–	10	–	–	2	17
	(BA)	–	–	4.4	–	–	4.9	–	–	1.6	10.9
Black locust	(#)	–	3	1	–	–	–	–	–	1	5
	(BA)	–	2.5	2.4	–	–	–	–	–	1.6	6.5
Black cherry	(#)	–	–	2	1	–	1	3	2	5	14
	(BA)	–	–	3.2	0.4	–	1.9	2.3	1.2	12.7	21.7
White ash	(#)	5	3	3	1	1	–	2	–	–	15
	(BA)	3.6	9.4	3.6	0.3	0.3	–	0.8	–	–	18.0
Other sp.‡	(#)	–	12	1	2	12	5	1	2	1	36
	(BA)	–	19.9	1.1	4.4	13.2	15.8	0.8	0.7	1.8	57.7
Totals	(#)	5	22	14	4	14	18	17	13	19	126
	(% of total stems)	14	88	29	7	33	42	28	36	50	
	(BA)	3.6	67.1	16.6	5.5	14.3	23.2	11.2	8.2	34.3	184
	(# of species)	1	4	6	4	5	6	5	4	6	

† Plots planted in WA = White ash, YP = Yellow-poplar, and WP = White pine.
‡ Other species are birch (*Betula* sp.), yellow-poplar, boxelder (*Acer negundo* L.), chokecherry (*Prunus pensylvanica* L. f.), sycamore (*Platanus occidentalis* L.), dogwood (*Cornus florida* L.), and basswood (*Tilia* sp.).

volunteers was found on the Dundee white pine and the Georgetown leveled yellow-poplar plots. These plots also had the lowest survival values of planted species. White pine plots on all areas had six volunteer tree species compared with one to five for the other planted tree plots, perhaps reflecting low competition from white pine and the opportunity for more species to invade into planted white pine than other planted species.

The Georgetown areas in 1992 were productive forest communities and the canopy was closed on most plots. White-tailed deer (*Odocoileus virginianus*), ruffed grouse (*Bonasa umbellus*), and rat snakes (*Elaphe obsoleta*) were observed on the site and earthworms (*Lumbricus terrestris*) were found in the minesoil. The trees on this site were not of exceptional timber quality. Many yellow-poplar trees were forked between the first and second log and many of the white pine had persistent dead lower branches, which is typical for this species. The forest community at Dundee in 1992 was similar to that described for Georgetown, but it tended to have more black cherry, maple (*Acer* sp.), and birch (*Betula* sp.). Many rodent burrows were found on both sites.

SUMMARY AND CONCLUSIONS

Four tree species were planted into leveled and unleveled alkaline overburden near Georgetown, OH, and also into unleveled acidic overburden at Dundee, OH, in 1946. Black locust had good initial survival at both sites but was destroyed in later years by the locust borer. White ash had the best survival of the three remaining species averaging 43% in both treatments at Georgetown and 33% at Dundee. Yellow-poplar had 3.3% survival on Georgetown leveled areas vs. 21% on unleveled areas, and 17% on Dundee unleveled areas. White pine survival varied from 14% on Dundee to 25% on Georgetown leveled areas. White pine and yellow-poplar grew taller on Georgetown unleveled vs. leveled areas, but there was no leveling treatment effect on white ash height. Tree height at Dundee was similar to Georgetown unleveled areas for all species. Minesoil bulk density was low on all areas (1.1 to 1.2 Mg/m^3) and the presumed initial difference in bulk density between Georgetown leveling treatments was not found. Large differences in acidic (pH 4.2) vs. alkaline (pH 7.7) minesoils did not translate into large differences in survival and height growth for these three trees on unleveled areas. Volunteer tree species were found in greater abundance and representing a greater percentage of the total basal area in plots where survival of planted species was low.

A commercial forest has gradually developed during the past 46 yr on both sites in Ohio with trees providing stabilization, potential economic returns, and wildlife habitat. Based on our results, white ash is recommended for tree planting during land reclamation because of its high survival and good growth on leveled and unleveled areas, and on acid and alkaline minesoils. Yellow-poplar survived poorly overall and white pine was intermediate. Commercial forests should be designated as a postmining land use on many surface mined sites in the eastern USA because of the benefits that accrue over time with trees.

ACKNOWLEDGMENTS

Special thanks go to Harry Wiant of West Virginia University for his support, advice, and help during this study. We also thank John Sencindiver of West Virginia University, Don Dickmann and Phu Nguyen of Michigan State University, and David Olszyk of U.S. Environmental Protection Agency, and two anonymous reviewers for excellent reviews and suggestions in preparing the manuscript. Acknowledgment also is given to Ms. Karen Tate for help in minesoil analyses and to Dr. Carl Ramm for statistics help.

REFERENCES

Brady, N.C. 1990. The nature and properties of soils. 10th ed. Macmillian Publ. Co., New York.

Brown, J.H. 1962. Success of tree planting on strip-mined areas in West Virginia. West Virginia Agric. and For. Exp. Stn. Bull. 473. West Virginia Univ., Morgantown.

Brown, J.H., and E.H. Tryon. 1960. Establishment of seeded black locust on spoil banks. West Virginia Univ. Agric. and For. Exp. Stn. Bull 440. West Virginia Univ., Morgantown.

Chapman, A.G. 1944. Forest planting on strip-mined coal lands with special reference to Ohio. Central States For. Exp. Stn. Tech. Pap. 104. USDA For. Serv., Columbus, OH.

Chapman, A.G. 1947. Rehabilitation of areas stripped for coal. USDA For. Serv. Central States For. Exp. Stn. Tech. Pap. 108. USDA For. Serv., Columbus, OH.

Czapowskyj, M.M., and W.E. McQuilkin. 1966. Survival and early growth of planted forest trees on strip-mine spoils in the anthracite region. USDA For. Serv. Res. Pap. NE-46. USDA For. Serv., Broomall, PA.

Dale, M.E., D.E. Lutz, and H.J. Bailey. 1989. Yield of white pine plantations in Ohio. North. J. Appl. For. 6:51-56.

Dowdy, S.M., and S. Wearden. 1991. Statistics for research. 2nd ed. John Wiley & Sons, New York.

Faulconer, R., J. Burger, S. Schoenholtz, and R. Kreh. 1996. Organic amendment effects on nitrogen and carbon mineralization in an Appalachian minesoil. p. 613-620. *In* Proc. Am. Soc. for Surface Mining and Reclamation Meeting, Knoxville, TN. 18-23 May 1996. Am. Soc. for Surface Mining and Reclamation and the Powell River Project of Virginia Tech., Blacksburg.

Finn, R.F. 1958. Ten years of strip-mine forestation research in Ohio. USDA For. Serv. Central States For. Exp. Stn. Tech. Pap. 153. USDA For. Serv., Columbus, OH.

Foil, R.R., and C.W. Ralston. 1967. The establishment and growth of loblolly pine seedlings on compacted soils. Soil Sci. Soc. Am. Proc. 31:565-568.

Forristall, F.F., and S.P. Gessel. 1955. Soil properties related to forest cover type and productivity on the Lee Forest, Snohomish County, Washington. Soil Sci. Soc. Am. Proc. 19:384-389.

Halverson, H.G., and R.P. Zisa. 1982. Measuring the response of conifer seedlings to soil compaction stress. USDA For. Serv. Res. Pap. NE-509. USDA For. Serv., Broomall, PA.

Hatchell, G.E., C.W. Ralston, and R.R. Foil. 1970. Soil disturbances in logging: effects on soil characteristics and growth of loblolly pine in the Atlantic Coastal Plain. J. For. 68:772-775.

Heilman, P. 1981. Root penetration of Douglas-fir seedlings into compacted soil. For. Sci. 27:660-666.

Heilman, P. 1990. Growth of Douglas fir and red alder on coal spoils in western Washington. Soil Sci. Soc. Am. J. 54:522-527.

Larson, M.M., and J.P. Vimmerstedt. 1983. Evaluation of 30-year-old plantations on stripmined land in east central Ohio. Ohio Agric. Res. and Devel. Ctr. Res. Bull. 1149. Ohio State Univ., Wooster.

Leak, W.B., P.H. Allen, J.P. Barrett, F.K. Beyer, D.L. Mader, J.C. Mawson, and R.K. Wilson. 1970. Yields of eastern white pine in New England related to age, site, and stocking. USDA For. Serv. Res. Pap. NE-176. USDA For. Serv., Columbus, OH.

Limstrom, G.A., and R.W. Merz. 1949. Rehabilitation of lands stripped for coal in Ohio. USDA For. Serv., Central States For. Exp. Stn. Tech. Pap. 113. USDA For. Serv., Columbus, OH.

Lindsay, W.L., and W.A. Norvell. 1978. Development of a DTPA soil test for zinc, iron, manganese and copper. Soil Sci. Soc. Am. J. 42:421-428.

Minckler, L.S. 1941. Forest plantation success and soil-site characteristics on old fields in the Great Appalachian Valley. Soil Sci. Soc. Am. Proc. 6:396-398.

Minore, D., C.E. Smith, and R.F. Woollard. 1969. Effects of high soil density on seedling root growth of seven northwestern tree species. USDA For. Serv. Res. Note PNW-112. USDA For. Serv., Wenachee, WA.

Perry, T.O. 1964. Soil compaction and loblolly pine growth. Tree Planters Notes 67:9.

Potter, H.S., S. Weitzman, and G.R. Trimble. 1955. Reforestation of stripped-mined lands. West Virginia Agric. and For. Exp. Stn. Mimeo. Circ. 55. West Virginia Univ., Morgantown.

Sawyer, L.E. 1949. The use of surface mined land. J. Soil Water Conserv. 4:161-165.

Schafer, W.M., G.A. Nielson, D.T. Dollhopf, and K.L. Temple. 1979. Soil genesis, hydrological properties, root characteristics, and microbial activity of 1- to 50-year-old stripmine spoils. Interagency Energy/Environment R&D Rep. USEPA-600/7-79-100. U.S. Gov. Print. Office, Washington, DC.

Schuster, W.S., and R.J. Hutnik. 1983. Strip-mine test plantings in Pennsylvania after 35 years. p. 119-128. *In* C. Kolar and W. Ashby (ed.) Proc. of Better Reclamation with Trees Conference, Terra Houte, IN. 2-3 June 1983. Purdue Univ., Lafayette, IN.

Simmons, G.L., and P.E. Pope. 1987. Influence of soil compaction and vesicular-arbuscular mycorrhizae on root growth of yellow-poplar and sweet gum seedlings. Can. J. For. Res. 17:970-975.

Simmons, G.L., and P.E. Pope. 1988. Influence of soil water potential and mycorrhizal colonization on root growth of yellow-poplar and sweet gum seedlings grown in compacted soil. Can. J. For. Res. 18:1392-1396.

Skousen, J.G., C.D. Johnson, and K. Garbutt. 1994. Natural revegetation of 15 abandoned mine land sites in West Virginia. J. Environ. Qual. 23:1224-1230.

Sobek, A.A., W.A. Schuller, J.R. Freeman, and R.M. Smith. 1978. Field and laboratory methods applicable to overburdens and minesoils. USEPA Rep. 600/2-78-054. U.S. Gov. Print. Office, Washington, DC.

Soil Survey Staff. 1984. Procedures for collecting soil samples and methods of analysis for soil survey. Soil Survey Invest. Rep. 1. USDA Soil Conserv. Serv., Washington, DC.

Torbert, J., and J. Burger. 1990. Tree survival and growth on graded and ungraded minesoil. Tree Planters Notes 41(2):3-5.

Torbert, J., and J. Burger. 1996. Influence of grading intensity on herbaceous ground cover, erosion, and tree establishment in the southern Appalachians. p. 637-646. *In* Proc. Am. Soc. for Surface Mining and Reclamation Meeting, Knoxville, TN. 18-23 May 1996. Am. Soc. for Surface Mining and Reclamation and the Powell River Project of Virginia Tech., Blacksburg.

Torbert, J., A. Tuladhar, J. Burger, and J. Bell. 1988. Minesoil property effects on the height of ten-year-old white pine. J. Environ. Qual. 17:189-192.

Tryon, E.H. 1952. Forest cover for spoil banks. West Virginia Agric. and For. Exp. Stn. Bull. 357. West Virginia Univ., Morgantown.

Waters, D.D., and L.E. Roth. 1986. Soil survey of Tuscarawas County, Ohio. USDA Soil Conserv. Serv., Columbus, OH.

Youngberg, C.T. 1959. The influence of soil conditions following tractor logging on the growth of planted Douglas-fir seedlings. Soil Sci. Soc. Am. Proc. 23:76-78.

Zisa, R.P., H.G. Halverson, and B.B. Stout. 1980. Establishment and early growth of conifers on compact soils in urban areas. USDA For. Serv. Res. Pap. NE-451. USDA For. Serv., Broomall, PA.