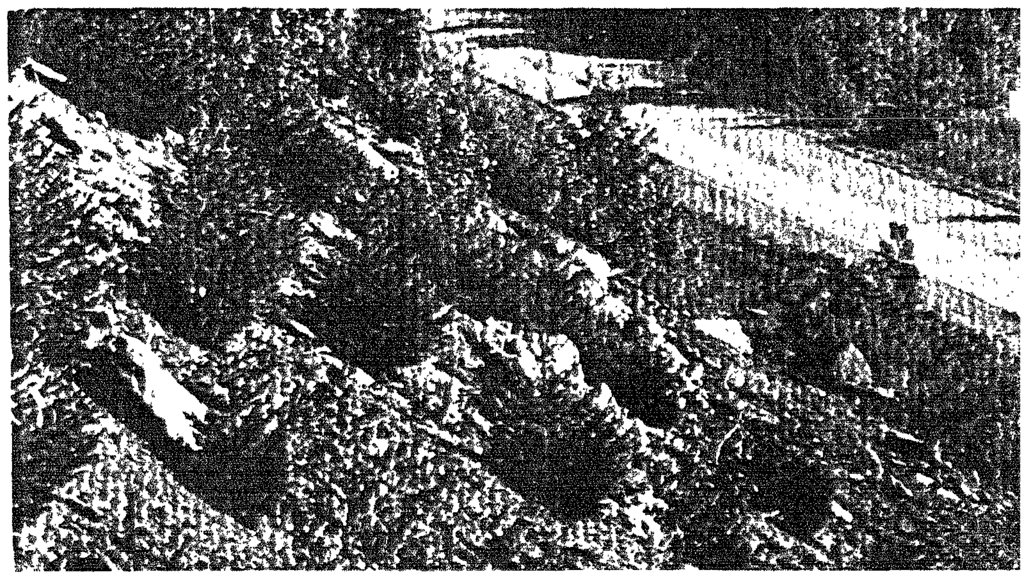
Survival and early growth of PLANTED forest trees on STRIP-MINE SPOILS in the anthracite region

by Miroslaw M. Czapowskyj
and William E. McQuilkin



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Preface

THIS is the second of several reports dealing with mine-spoil revegetation research in the Anthracite Region of Pennsylvania. The first report, published in 1964, was "A guide for screen and cover planting of trees on anthracite mine-spoil areas" (U.S. Forest Service Research Paper NE-22). Other reports, describing results of studies still in progress, are scheduled for publication in the future.

The Pennsylvania Power and Light Company, whose interest led to initiation of this project on anthracite mine-spoil revegetation in 1961, financed most of the research reported in this and the preceding report, and is continuing its financial support of the studies now in progress.

The Pennsylvania Department of Forests and Waters and the Pennsylvania Department of Mines and Mineral Industries made their records available as an aid in locating plantations established under the State's strip-mine laws. Also, Joseph Paddock and Con Postupack, contract planters, made their records available and personally helped find and identify many of the plantations in the field. This co-operation and assistance, without which this study would have been severely handicapped, is gratefully acknowledged.

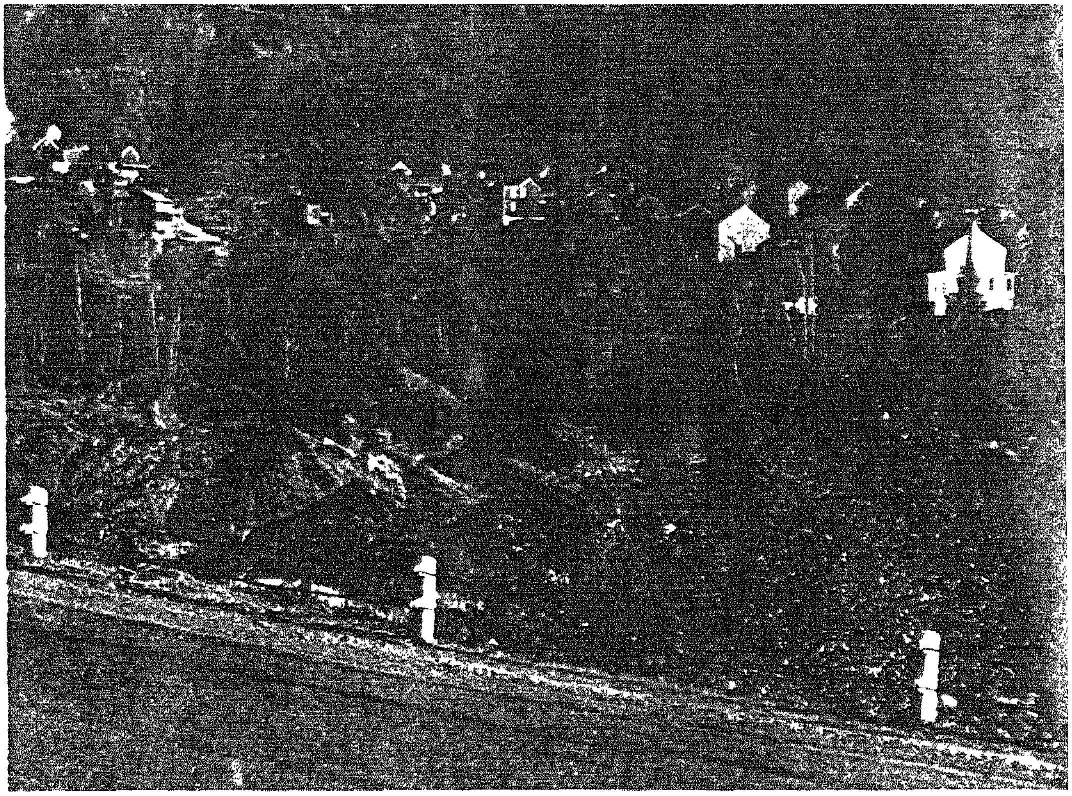

Figure 1.—Many communities in the Anthracite Region are surrounded by a panorama of unsightly coal-mine spoils. This is Girardville, in Schuylkill County.

Introduction

THE Anthracite Region of Pennsylvania once was blessed with a wealth of natural resources. Verdant mountain landscapes, interlaced with sparkling streams, spread as far as the eye could see. Magnificent forests clothed the land, and for a time supported a great lumber industry. Underlying the synclines in massive folds of the rock formations were the world's finest deposits of anthracite coal.

Beginning in the early 1800's, the mining of these coal deposits expanded to become the dominant industry of the Region, reaching its peak in the period 1910-30. Production slumped during the depression of the 1930's, rose again somewhat during World War II, and then slid into a decline that has continued to the present day.

Until rather recently, practically all anthracite was mined by sinking shafts deep into the earth, and the landscape was marred only by huge piles of waste near the mine entrances and the coal breakers. Then, in the 1930's, large-scale strip-mining ushered in a new era in the exploitation of the coal resource. To get at the coal seams, the overburden was stripped off with great earth-moving machines, and open-pit methods were used to dig out the coal.

Open-pit mining no doubt bolstered the economic health of the anthracite industry, but it has had detrimental side effects: it disturbs considerably more land than deep mining, and leaves much more barren residue. Particularly since World War II, stripping has become increasingly predominant in anthracite production, and consequently landscapes in the coal fields are almost universally scarred by stripping operations.

According to a recent survey conducted by the Northeastern Forest Experiment Station of the U.S. Forest Service in cooperation with the Pennsylvania Power and Light Company, the total area classified as disturbed by mining up to 1962 approximated 112,000 acres. Of this acreage, 76 percent was due to strip-mining (Frank, 1964). More than half of the stripped land is practically devoid of tree cover. In all, 19 percent of the total area in the coal fields has been physically disturbed. The scarring of the landscape, the contamination of streams and reservoirs by acids, soluble iron, and silt, and the discomforts of windblown dust around active strippings — all conspire to create depressing conditions for people living in these areas (fig. 1).

The seriousness of the situation has long been recognized by public agencies, civic and private organizations, certain coal companies, and many individuals. It has long been recognized, also, that one of the most effective ways to correct the situation is to establish vegetation wherever possible on the disturbed areas.

In 1938 Stanley Mesavage, then forester for the Susquehanna Collieries Company, put in some small-scale tree plantings[1] that are believed to be the first planting trials on anthracite spoils. In 1940, C. E. Ostrom of the Allegheny Forest Experiment Station (predecessor of the present Northeastern Station) made a preliminary survey of the planting problem on anthracite spoils.[1] And in 1943, W. E. McQuilkin of the Northeastern Station conducted some greenhouse studies of spoil acidity and fertility.[1]

Neither Ostrom nor McQuilkin did further work on the spoil problem at that time. However, Joseph Paddock, forester attached to the Wilkes-Barre Chamber of Commerce, continued Mesavage's trials by making additional small plantings in the early 1940's. The first experimental plantings of a formal nature were started in 1944 by the Pennsylvania Department of Forests and Waters (Mickalitis and Kutz, 1949).

In 1947, the Legislature of the Commonwealth of Pennsylvania enacted the first anthracite strip-mining law (Commonwealth of Pennsylvania, 1947). This required strip-mine operators to post bond for their stripping operations. Upon completion of an operation, the operator was required to plant trees, shrubs, or grasses on the spoil area, or, at his option, to forfeit $60 per acre of the bond in lieu of planting. The Department of Forests and Waters administered the tree-planting section of this law until 1953. Then the law was amended (Commonwealth of Pennsylvania, 1953) and administration of tree planting became a function of the Department of Mines and Mineral Industries. In 1963, the law was again amended (Commonwealth of Pennsylvania, 1963). This latest amendment set considerably higher specifications for grading and leveling than the previous laws, and the portion of the bond designated to cover the planting was increased to $100 per acre. As before, an operator can forfeit this portion of the bond and be released from all planting obligations.

[1] Unpublished records and reports on file at the Kingston unit of the Northeastern Forest Experiment Station.

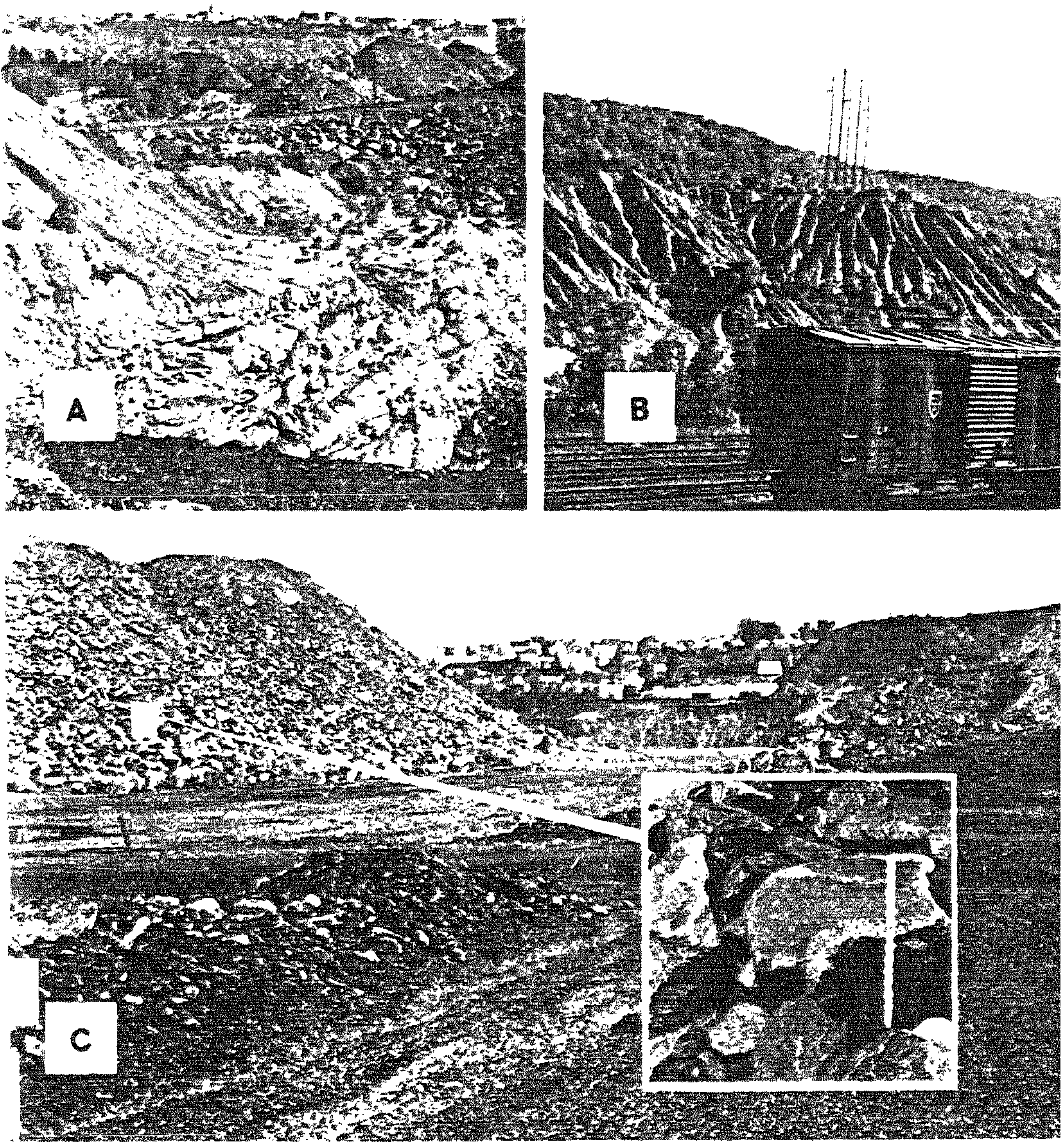

Figure 2.—Barren areas of strip-mine spoil. Although most spoils can be planted, portions of some old ungraded spoils are unplantable because of steepness of slopes as in A, right foreground; or erosion as in B; or excessive stoniness as in C, left background and inset. The grading provisions of the present strip-mine law do not permit such conditions to remain now when strippings are completed.

Although the experimental plantings by the Department of Forests and Waters during the period 1944-50 totaled some 200,000 trees, the results were not conclusive because of failures and losses to re-stripping. No other organized research had been done up to 1962. Hence both the planting under the strip-mining law and the occasional other private planting on spoil areas were based largely on experience on other types of sites.

Since the first small plantings in 1938, about 6 million trees were estimated to have been planted by 1962 in the four anthracite coal fields.[2] The results have been variable and erratic: some successes and partial successes, but also numerous failures (and losses to re-stripping). In 1962, when the present study was undertaken, the performance of these plantings was known only in a general way from informal observations. Survival and growth of the various species in relation to spoil types and other site conditions had never been drawn together in an organized study.

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[2] Paddock, Joseph (Industrial Forester, Greater Wilkes-Barre Chamber of Commerce), personal communication, 1962.

The Study

In 1962 a survey-type study was conducted to evaluate the performance of forest tree species in established plantings on strip-mine spoils of the Anthracite Region of Pennsylvania. Plantations representing a wide range of site conditions in all four anthracite fields were examined.

The spoils were classified into four major types on the basis of parent material and acidity expressed as pH. Subdivisions within these types were recognized with respect to texture, aspect, slope position, and grading treatment. In each plantation that qualified for study, height measurements and survival counts were taken by species, and the spoil type and other site characteristics were recorded. Region-wide species performances were then correlated with spoil types and conditions.

The results of the study provide the basis for a preliminary guide for forest tree planting on the spoils. They also serve to identify the most crucial gaps in our knowledge and thus indicate where additional research effort should be directed.

Because anthracite and bituminous strip-mine spoils, although different in some respects, are basically similar, experience gained in a recent survey of established plantations on bituminous spoils (Davis and Melton, 1963; Hart and Byrnes, 1960) was utilized in planning the present study. Certain modifications were introduced to fit anthracite conditions.

LOCATING THE PLANTATIONS

The initial step in locating plantations was to check records on file with the Department of Forests and Waters and the Department of Mines and Mineral Industries. This was followed by an intensive search in the field with the assistance of contract planters and others having knowledge of past plantings. The number of suitable plantations was much fewer than originally anticipated. Furthermore, many of the plantations were so small, the spoil banks were so variable, and some species were so infrequently represented, that all hope of thoroughly sampling all the species across a balanced series of site variations had to be abandoned. Nevertheless the plantings did cover considerable variation in spoil material and other site factors, and much worthwhile information on the more commonly used species was obtained.

TREE AND PLANTATION DATA

For comparative data on height growth, measurements at a standard age were required. Moreover, both height and survival data are more meaningful if taken several years after trees are planted. In view of these considerations and the availability of plantings of different ages, 7 years was selected as the standard plantation age for most of our sampling. Six- and 8-year-old plantations also were sampled and lumped with the 7-year ones after converting the tree heights to a 7-year basis by adding or subtracting, respectively, the length of the last year's growth. All plantations in this 6- to 8-year age range that were suitable for our purposes were sampled.

A few older plantings, ranging from 10 to 18 years old, also were sampled. Most of these were in the northern field (Susquehanna–Lackawanna Valley area). The predominant species was black locust that had been planted in 1950. Older plantings of conifers were relatively scarce.

Sampling was done by plots of a single species. The usual plot in 7-year plantations comprised 25 original planting spots about equally divided between two or three adjacent rows. Where rows

Table 1.—*Species studied and number of plots taken, by species and age class*

Species		Plots in age classes (years)—		
Common name	Scientific name	7 (±1)	10-18	Total
Jack pine	*Pinus banksiana*	34	4	38
Red pine	*Pinus resinosa*	15	4	19
White pine	*Pinus strobus*	7	1	8
Virginia pine	*Pinus virginiana*	2	1	3
Pitch pine	*Pinus rigida*	2	2	4
Scotch pine	*Pinus sylvestris*	1	3	4
Norway spruce	*Picea abies*	43	—	43
White spruce	*Picea glauca*	27	—	27
Japanese larch	*Larix leptolepis*	21	3	24
European larch	*Larix decidua*	13	4	17
Black locust	*Robinia pseudoacacia*	—	11	11
All species		165	33	198

could not be identified, a plot of such dimensions that it could be assumed to have originally contained 25 trees at 6- x 6-foot spacing was roughly delimited. Where different species or different site conditions were represented in a plantation, two or more plots were taken in the same vicinity to sample the various situations.

A total of 198 usable plots were taken. Of these, 165 represented the 7-year age class, and 33 represented the 10- to 18-year class (table 1). Survival, vigor, and height were recorded for the trees on each 7-year plot as explained below:

Survival. — Starting at a randomly selected point, trees were tallied as living, dead, or missing in consecutive planting spots along the two or three selected rows until 25 spots had been checked. If rows could not be identified, the tally was based on an assumed distribution of planting spots. Trees that had recently been cut or destroyed but obviously had been living at that time were counted among the survivors.

Tree vigor. — Each tree included in the survival count was classified into one of five vigor classes: 1 — excellent; 2 — good; 3 — fair; 4 — poor; or 5 — very poor. Through use of the numerical ratings, average vigor for plots or other groups of trees could be calculated. The classes were based on color and density of foliage and on tree form, according to criteria defined in the earlier study in the bituminous region (Hart and Byrnes, 1960).

Height growth. — At each sampling point, 10 trees were measured for height to the nearest 0.1 foot. These 10 trees usually were selected among those in the survival count, and were distributed among the five vigor classes roughly in proportion to the distribution of all the survivors; that is, if one-third of the survivors fell in a given vigor class, three trees of this class were measured for height; if one-half the survivors fell in a given class, five of them were measured, and so on. Selections of trees within vigor classes were at random, except that overtopped trees or those with dead or broken terminals were not used. Some of the 25-spot plots checked for survival did not yield 10 trees suitable for height measurement; in these situations, enough other trees growing nearby under similar conditions were selected to provide a 10-tree sample. This was most often necessary for the plots with unidentifiable rows because high mortality often was responsible for the loss of row definition.

In the older plantings, the 11 plots of black locust were all 12 years old. Essentially the same data were taken here as in the 7-year plantings, except that survival was determined in 0.1-acre plots. The miscellaneous 10- to 18-year-old plantings of conifers were so patchy and irregular that conventional plot methods of sampling were not suitable, and reliable estimates of survival could not be obtained. So we worked with whatever small groups of trees happened to be growing together under seemingly similar site conditions. Data taken for each such group included site characteristics, tree age, vigor, diameter of each tree at breast height to the nearest 0.1 inch, and height of at least six trees (if available) to the nearest foot.

DATA ON SPOIL AND SITE CHARACTERISTICS

Anthracite strip-mine spoils are composed of unstable debris of rock, coal, glacial till (mostly in the northern field) and surface soil. This material exhibits great diversity in physical and chemical characteristics; it varies widely not only from one spoil bank to another, but also on the same bank. Consequently, each bank is to some degree a unique problem. As tree-planting media these spoils have thus far received relatively little attention by soil scientists.

The initial step in collecting data on spoil characteristics was to devise a practical system of classification. The result was a rather simple classification in which four types of spoil were distinguished on the basis of the parent material. Our system was a modification of a classification developed by Bramble, Deitschman, and Keppler (1948) in their work on spoils in the Bituminous Region of Pennsylvania.

The four spoil types, number of plots in each, and a brief description are listed below:

Spoil type I — 51 plots: Coarse, black to dark gray, thin-bedded carbonaceous shales and slates, plus coal fragments. Gray to yellow thick-bedded slaty shales, sandstones, and conglomerate fragments are commonly associated.

Spoil type II — 73 plots: Pale gray to yellow, soft, thick-bedded shale and slate fragments, with black shales, and sandstones frequently intermixed.

Spoil type III — 39 plots: Gray to brown acid sandstone and conglomerate fragments. Slates and shales, together with glacial and stream deposits, often are associated. Extreme stoniness, with rocks 4 or more feet in diameter, is a common occurrence.

Spoil type IV — 35 plots: Basically glacial till and stream deposits, but sandstone, conglomerates, slates, and shale fragments may be associated. The coarse elements of the till and stream deposits vary from 2 millimeters to 2 inches in diameter. However, elements larger than 2 inches in diameter are occasionally present.

Each sampling point or plot was classified according to:

1. Spoil type: I, II, III, IV.
2. Grading treatment: graded or ungraded.
3. Degree of slope: steep—40-70 percent, medium—20-40 percent, or gentle—0-20 percent.
4. Aspect by cardinal compass points: north, south, east, or west.

In addition, a spoil sample of about 4 pounds was taken from each of three randomly selected spots in each plot. Sampling was restricted to bare surfaces.

In the laboratory, the following determinations were made:

1. Acidity. — determined on each sample with a Beckman Zeromatic pH meter. The pH tests were run on mixtures of the smaller rock fragments and finer material. Aqueous solutions 1:1 were used.

2. Rock content. — determined on composites of the three samples from each sampling point after the separate pH tests had been made. Rock content was the percentage of total air-dry weight that would not pass a 2-millimeter sieve.

3. Texture of the soil fraction. — also determined on the composite samples. The soil fraction was the material that passed a 2-millimeter sieve. Determinations were made by a modification of the Bouyoucos method (Bouyoucos, 1936).

Table 2 shows the distribution of the plots in each spoil type by textural classes of the soil fraction, and by four acidity classes. Note particularly in this table the tendencies toward finer or heavier textures, and toward lower acidity (higher pH), in type IV.

Table 2.—*Distribution of plots in each spoil type, by textural classes of the soil fraction and by four acidity classes*

Spoil type	Textural classes					Acidity (pH)				Average acidity
	Sand and loamy sand	Sandy loam	Loam	Clay loam	Sandy clay loam	4.0 and lower	4.1 to 5.0	5.1 to 6.0	6.1 and higher	
	— Percent of plots —					*— Percent of plots —*				*pH*
I	4	90	2	2	2	20	63	8	9	4.4
II	0	68	1	9	21	8	65	15	12	4.8
III	8	69	2	3	18	0	80	10	10	4.8
IV	3	43	26	20	8	0	14	80	6	5.3

Results

Because it was impossible to find all species of the same age under all environmental conditions on all spoil types, only limited use could be made of statistical methods of data analysis. The conventional analysis of variance could not be used for comparing survival and growth among species or among different site categories. Therefore the study results are presented in a set of tables in which the data on survival and growth are summarized, by species, without statistical evaluations.

SURVIVAL AND GROWTH OF 7-YEAR-OLD PLANTINGS

Average survival and average tree height are shown by species for all 7-year sample plots in tables 3 and 4, respectively. Figure 3 depicts some of the same data graphically.

In table 3, the plots of each species are broken down into four survival classes: very good — 81-100 percent; good — 61-80 percent; adequate — 41-60 percent; and poor — 0-40 percent. Under each genus, the species are listed in descending order by number of plots studied.

Table 4 shows, besides average heights, the ranges in height, the growth in 1962, and average tree vigor according to the previously noted numerical scale. In comparing height growth of the various species, it should be remembered that rate of juvenile growth is a characteristic that varies considerably among species. For instance, jack pine and the larches normally grow faster during the early years than many other conifers; spruces, on the other hand, normally grow more slowly. Therefore, height should not be the sole criterion in judging the suitability of different species for planting spoil areas. Tree condition and vigor, which help to indicate the adaptability of a species to the site, also are important.

Tables 5 to 7 present more detailed data on survival and height growth in relation to spoil types, acidity of the spoils, and grading. The following discussions of individual species are based largely on data presented in these tables.

Figure 3.—Average survival and height, by species, of trees in all sample plots 7 years after planting. Figures at the bottom of the bars indicate the number of plots studied. For black locust, 7-year data were not obtained; survival shown is based on 12-year-old plantings.

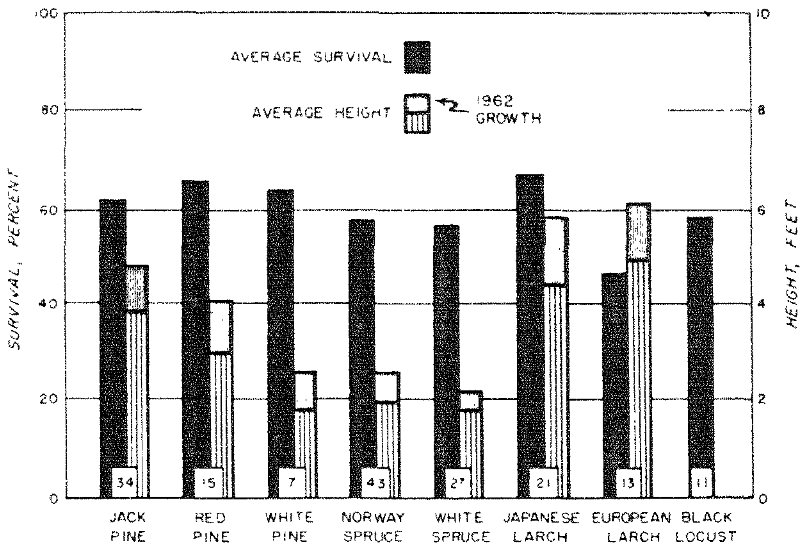


Table 3.—*Survival of 7-year-old plantings, by species*

Species	Average survival	Plots with survival of — 81 to 100	61 to 80	41 to 60	0 to 40	Total
	Percent		— *Percent of plots* —			
Jack pine	62	18	38	21	23	100
Red pine	66	20	33	40	7	100
White pine	64	—	29	71	—	100
Virginia pine[1]	60	—	50	50	—	100
Pitch pine[1]	90	100	—	—	—	100
Scotch pine[1]	70	—	100	—	—	100
Norway spruce	58	—	49	23	28	100
White spruce	57	4	26	41	29	100
Japanese larch	68	19	33	48	—	100
European larch	47	—	38	—	62	100
Black locust[2]	59	9	18	64	9	100

[1] Represented by only 1 or 2 plots.
[2] Based on 12 years after planting.

Table 4.—*Height growth and vigor of trees in 7-year-old plantings, by species*

Species	Height			Vigor[1]		1962 height growth	
	Plots	Plot average	Plot range	Plot average	Plot range	Plot average	Plot range
	No.	*Feet*	*Feet*	*Numerical rating*		*Feet*	*Feet*
Jack pine	34	4.8	2.2–8.5	3.1	1.3–4.7	1.0	0.3–1.7
Red pine	15	4.1	2.8–4.6	3.1	1.9–3.7	1.1	.6–1.4
White pine	7	2.6	.8–4.5	3.7	2.0–4.9	.8	.1–1.6
Virginia pine[2]	2	5.7	5.6–5.8	3.0	2.7–3.2	1.1	.8–1.3
Pitch pine[2]	2	3.5	3.0–4.0	3.5	3.2–3.7	.7	.6–0.7
Scotch pine[2]	1	4.1	—	2.4	—	1.1	—
Norway spruce	43	2.6	1.2–7.6	2.9	1.0–4.2	.6	.2–1.3
White spruce	27	2.2	1.1–3.6	3.2	2.7–4.3	.4	.2–1.0
Japanese larch	21	5.9	1.0–12.6	3.1	1.5–5.0	1.4	.1–3.4
European larch	13	6.2	1.8–10.6	2.6	1.4–4.1	1.2	.3–2.3
Black locust[3]	11	30.1	24.2–39.2	—	—	—	—

[1] Rated numerically: 1 = excellent to 5 = very poor.
[2] Data weak because of small number of plots.
[3] Based on the performance of 12 growing seasons.

Table 5.—*Average survival, in percent, and average height, in feet, at 7 years of age as related to spoil type*

Species	Plots	Spoil type								Weighted average	
		I		II		III		IV			
	No.	*%*	*Ft.*	*%*	*Ft.*	*%*	*Ft.*	*%*	*Ft.*	*%*	*Ft.*
Jack pine	34	—	—	52	5.1	76	4.3	59	5.0	62	4.8
Red pine	15	76	4.4	44	2.6	72	3.9	57	3.9	66	4.1
White pine	7	—	—	80	2.3	60	4.5	61	2.2	64	2.6
Virginia pine	2	—	—	60	5.7	—	—	—	—	—	5.7
Pitch pine	2	—	—	—	—	90	3.5	—	—	—	3.5
Scotch pine	1	—	—	70[1]	4.1	—	—	—	—	—	4.1
Norway spruce	43	54	2.3	62	3.0	64	1.9	—	—	58	2.6
White spruce	27	55	2.1	61	2.5	55	1.9	—	—	57	2.2
Japanese larch	21	68	6.0	72	7.7	67	6.1	66	3.0	68	5.9
European larch	13	44	8.2	42	5.6	30	2.7	80	7.0	47	6.2
Black locust[2]	11	61	30.4	62	32.3	35	24.2	—	—	59	30.1

[1] Estimated.
[2] Based on 12 years' growth.

Table 6.—*Average survival, in percent, and average height, in feet, at 7 years as related to acidity classes*

Species	Plots	Acidity classes in pH values														Weighted average	
		3.5–3.9		4.0–4.5		4.6–5.0		5.1–5.5		5.6–6.0		6.1–6.5		6.6–7.4			
	No.	*%*	*Ft.*	*%*	*Ft.*	*%*	*Ft.*	*%*	*Ft.*	*%*	*Ft.*	*%*	*Ft.*	*%*	*Ft.*	*%*	*Ft.*
Jack pine	34	—	—	74	4.5	72	5.5	55	5.2	58	4.2	34	4.0	—	—	62	4.8
Red pine	15	—	—	75	4.3	—	—	64	3.9	52	4.4	—	—	44	3.2	66	4.1
White pine	7	—	—	—	—	—	—	64	2.6	60	4.5	60	.8	—	—	64	2.6
Virginia pine	2	—	—	—	—	—	5.6	—	5.7	—	—	—	—	—	—	—	5.7
Pitch pine	2	—	—	—	3.5	50	—	70	—	—	—	—	—	—	—	—	3.5
Scotch pine	1	—	—	—	—	—	—	70[1]	—	—	4.1	—	—	—	—	—	4.1
Norway spruce	43	52	1.7	63	2.5	71	2.7	56	3.2	20[1]	2.3	60	2.4	53	2.4	58	2.6
White spruce	27	66	2.3	57	2.0	62	2.1	49	2.9	—	—	72	1.6	45	2.4	57	2.2
Japanese larch	21	67	8.5	72	6.7	62	5.4	78	3.4	—	—	53	4.7	—	—	68	5.9
European larch	13	—	—	38	5.0	39	6.0	80	7.6	76	8.5	—	—	—	—	47	6.2
Black locust[2]	11	—	—	53	27.4	59	31.3	70	35.8	—	—	—	—	—	—	59	30.6

[1] Estimated value.
[2] Based on 12 years' growth.

Table 7.—*Average survival, in percent, and average height, in feet, at 7 years as related to grading*

Species	Plots	Graded		Ungraded		Weighted average	
	No.	*%*	*Ft.*	*%*	*Ft.*	*%*	*Ft.*
Jack pine	34	63	4.6	64	5.1	62	4.8
Red pine	15	65	4.1	—	—	66	—
White pine	7	63	2.6	—	—	64	—
Virginia pine	2	70	5.7	50	5.6	60	5.7
Pitch pine	2	90	3.5	—	—	—	—
Scotch pine	1	70	4.1	—	—	—	—
Norway spruce	43	54	1.8	59	2.7	58	2.6
White spruce	27	62	1.5	56	2.4	57	2.2
Japanese larch	21	63	2.7	70	7.1	68	5.9
European larch	13	68	5.9	35	6.7	47	6.2
Black locust[1]	11	52	29.1	62	31.3	59	30.1

[1] Based on 12 years' growth.

Jack Pine

Little difference in overall average survival occurred among the pine species that were adequately sampled. However, jack pine plots exhibited the most nearly equal distribution among survival classes from very good to poor (table 3). Survival of jack pine appeared to be affected by spoil type: it was good on type III, but only adequate on types II and IV. No jack pine plots were obtained on type I. Survival seemed to decrease with increased spoil pH within the range from extremely acid to medium acid. Grading had no apparent effect on survival of this species.

For all plots, jack pine averaged 4.8 feet tall. However, heights varied widely among plots. Growth tended to be somewhat better on the more acid spoils (pH 4.6 to 5.0). No definite effects on growth could be attributed to spoil type or to grading, but some trees on lower slopes were as much as 1.5 feet taller than those on upper slopes.

Red Pine

Red pine was the only pine species found on all four spoil types. However, all plots of this species were on graded areas; so no comparison of its performance on graded versus ungraded spoils was possible.

Survival ranged mostly from adequate to very good. It was poor on only one plot. Both spoil type and acidity seemed to affect survival: types I and III, which were more acid than types II and IV, showed the better survival. The relation of red pine survival to acidity was similar to that of jack pine — best at pH 4.0 to 4.5 and decreasing with higher pH.

Average height for all plots was 4.1 feet. The best growth occurred on spoil type I where survival also was best. However, growth on types III and IV averaged only 0.5 foot less. Growth tended to be poorer with increasing clay content of the spoil and with increasing pH. These trends, although not strongly evident in the tabulated summaries, were indicated by analyses of individual plot data. We can only speculate about the effect of grading; but from general knowledge of the silvics of red pine, we may assume that this species would grow fully as well, and perhaps better, on ungraded areas than on the graded areas where all the plots were found (fig. 4).

Figure 4.—Seven-year-old red pine plantation near Atlas, Pa., on graded spoil type I of pH 3.8 to 4.5. Survival here was 70 percent, average height 4.5 feet.

White Pine

Because only seven plots of white pine were obtained, the data are relatively weak for judging performance of this species under different spoil conditions. Survival was adequate to good on graded spoils of types II, III, and IV (no plots on type I). On type II, where jack and red pines showed their lowest survivals, white pine survival was better than on the other types. All white pine plots fell in the acidity range of pH 5.1 to 6.5; and within this range acidity exerted no appreciable effect on survival.

Average height was 2.6 feet — considerably less than the averages for red and jack pines, and more comparable to the growth of spruces. White pine heights varied a great deal. Growth tended to be better on lower slopes than on upper slopes.

Virginia, Scotch, and Pitch Pines

Each of these species was represented on only one or two plots. Survivals were as good as, or better than, survivals of the other pines. Height growth was somewhat less variable than that of the other pines. Virginia pine growth, which averaged 5.7 feet, was comparable to the best growth of jack pine; similar growth rates by these two species are common also on other kinds of sites. The height growth of Scotch and pitch pines, at 4.1 and 3.5 feet, was comparable to that of red pine. These similarities, too, are common on other sites.

Norway and White Spruces

These two species behaved similarly and therefore can be discussed together. The two species provided 70 plots, but none of these was on spoil type IV. Survival was poor on more than a fourth of the plots. It rated very good on one white spruce plot, and adequate to good on all others.

Survivals did not vary appreciably among spoil types I, II, and III, and they showed no consistent trend in relation to spoil acidity. Differences in survival between graded and ungraded plots were small and probably insignificant.

Average height for Norway spruce was 2.6 feet, and for white spruce 2.2 feet. Slow growth during the early years is normal for spruces; therefore these heights do not necessarily mean that the species are failing. The best growth of both species occurred on spoil type II and at pH 5.1 to 5.5. Growth tended to be less at both higher and lower acidities. Height growth of both species was definitely better on ungraded areas than on graded areas (fig. 5).

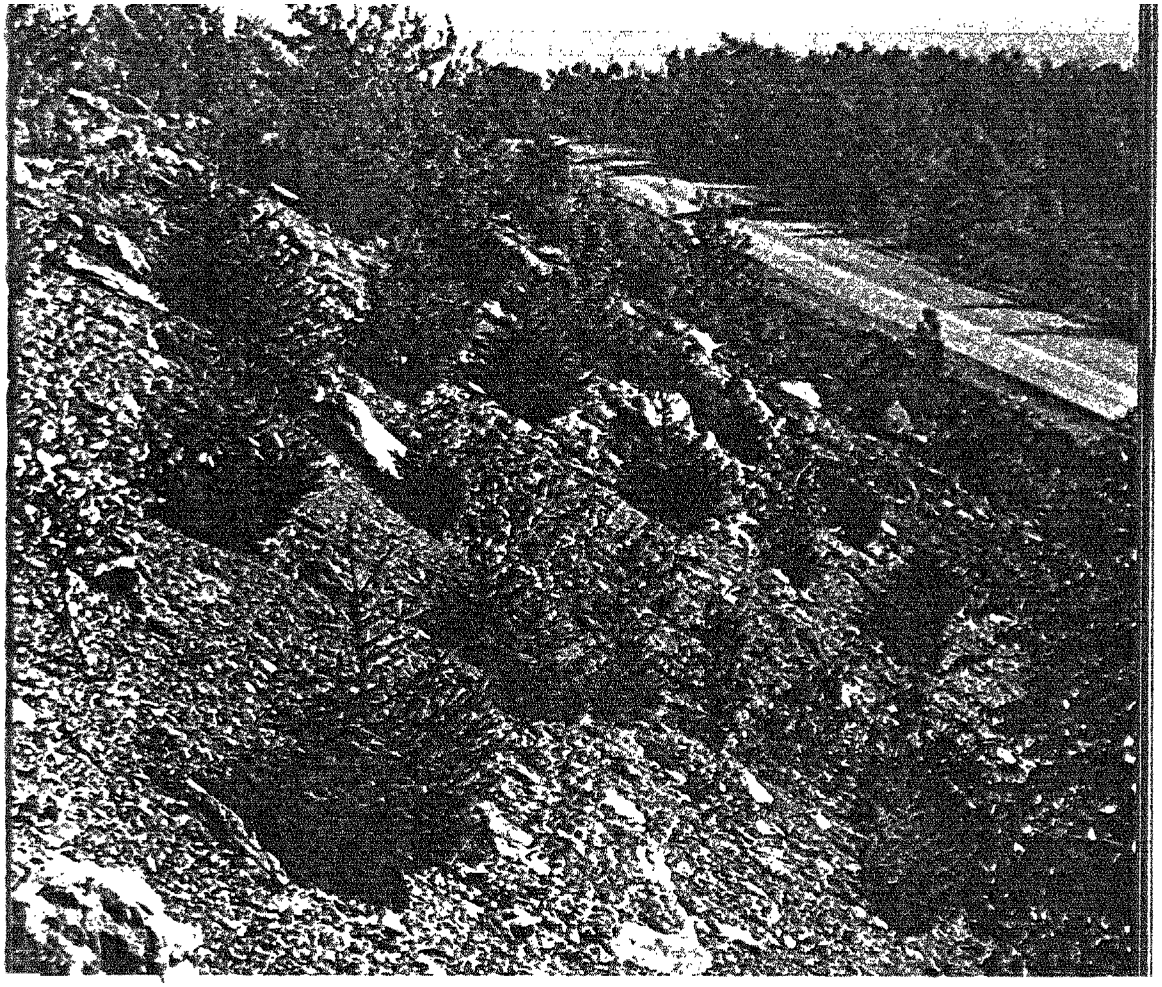


Figure 5.—Seven-year-old white spruce plantation in the vicinity of St. Clair, Pa., on ungraded spoil type II of pH 4.6 to 4.8. Average height, 2.0 feet.

Japanese Larch

Japanese larch survived almost equally well on all four spoil types. Survivals ranged from adequate to very good, averaging good for all plots collectively. Survivals were good at all pH levels below 5.5, even in spoils of pH 3.5 to 3.9. At pH 6.1 to 6.5, survival was only adequate. Survival was slightly better on ungraded than on graded areas.

Average height for all plots was 5.9 feet. Best growth occurred on spoil type II (average 7.7 feet), and poorest on type IV (average 3.0 feet). Height growth seemed to be correlated with acidity:

growth was best in the pH range of 3.5 to 4.0 and tended to decrease with decreasing acidity of the spoil. Growth was markedly better on ungraded areas than on graded areas, and on ungraded areas it was substantially better on upper slopes than on lower slopes. This is contrary to the usual effect of slope position.

European Larch

European larch survived less successfully than Japanese larch. Survival was poor on spoil type III, barely adequate on types I and II, and good only on type IV. The overall average survival was adequate (47 percent). All plots fell in the pH range of 4.0 to 6.0; and within this range survival was about twice as high above pH 5.0 as below pH 5.0. European larch seems definitely to be less tolerant of high acidity than the Japanese species. The two species also differed sharply in response to grading: survival of European larch was almost twice as high on graded areas as on ungraded areas, whereas Japanese larch survived slightly better under conditions of no grading.

In height growth, European larch slightly exceeded Japanese larch in the overall averages, and the relationships with spoil type were quite different. The best average European larch growth occurred on type I and the poorest on type III. The different responses to spoil type may be primarily responses to acidity. As table 6 shows, European larch growth increased with increasing pH, whereas the trend in Japanese larch was directly opposite. Despite the much better survival of European larch on graded areas, its growth averaged somewhat better on ungraded areas. The growth of both species was exceedingly variable, even within spoil types and under what appeared to be similar conditions.

PERFORMANCE OF OLDER PLANTINGS

Older plantings (10 to 18 years) are discussed below under two headings, (1) black locust, and (2) conifers. Much more black locust was available for study, and different data were taken than for the older conifers. Except that the locust plots were 0.1 acre in size, the locust data were taken in the same manner as in the 7-year conifer plantings, and are included in the 7-year tables. Because only a few trees of the older conifers were available in many instances, survival data were not taken. The growth and site data for these small groups of trees are presented in table 8.

Table 8.—*Performance of older conifer plantations and associated spoil characteristics*

Species	Age	Trees	Height Average	Height Range	Average d.b.h.	Spoil type	Rock content	Textural classification	Acidity Average	Acidity Range
	Years	*No.*	*Feet*	*Feet*	*Inches*		*Percent*		*pH*	*pH*
Jack pine	10	7	5.0	3.0–6.5	—	I	80	Sandy loam	3.9	3.7–4.1
	10	6	14.5	13.8–15.6	3.1	I	45	Sandy loam	4.0	3.7–4.2
	11	6	12.8	10.5–14.0	—	II	55	Loam	4.5	4.4–4.5
	11	10	10.4	6.0–14.0	—	IV	30	Sandy loam	5.1	4.7–5.4
Red pine	10	10	12.9	8.2–15.3	2.4	I	75	Sandy loam	4.0	3.6–4.4
	10	8	15.9	10.5–20.4	2.7	II	40	Sandy loam	4.7	4.6–4.7
	12	8	12.8	10.8–15.6	2.3	I	75	Sandy loam	4.9	4.4–5.6
	18	10	17.2	14.2–22.0	4.0	II	60	Sandy loam	3.8	3.7–4.0
White pine	18	10	24.3	20.0–28.0	4.7	II	50	Sandy loam	4.3	4.0–4.5
Virginia pine	10	4	4.6	3.7–5.1	—	III	80	Sandy loam	3.9	3.7–4.1
Pitch pine	11	10	12.6	10.5–14.6	—	I	55	Sandy loam	4.4	4.2–4.7
	11	6	9.3	8.0–11.0	—	II	55	Sandy loam	4.5	4.4–4.5
Scotch pine	10	16	14.1	10.0–19.5	2.2	III	75	Sandy loam	4.4	4.0–5.1
Japanese larch	10	6	17.1	13.6–25.0	3.4	III	55	Sand	4.7	4.5–4.9
	10	6	21.0	17.5–25.8	4.2	I	55	Sandy loam	4.0	3.9–4.1
	13	5	29.2	27.0–33.5	5.3	II	80	Sandy loam	6.7	6.2–7.2
European larch	12	20	22.8	12.5–30.5	3.2	II	45	Sandy loam	5.2	4.8–6.0
	13	10	24.7	17.3–32.0	4.3	II	50	Sandy loam	6.3	6.2–6.5

Black Locust

Most of the black locust plots were on spoil types I and II. Survivals were mostly adequate to good. One plot on spoil type III showed poor survival. Within the pH range of 4.0 to 5.5, which included all the locust plots, survival increased with increasing pH. Survival was slightly better on ungraded areas than on graded areas (fig. 6).

Figure 6.—Fifteen-year-old black locust plantation in Newport Township, Pa., on graded spoil type II of pH 4.4. Survival and growth were sufficient to provide almost complete canopy. A ground cover of herbs and low shrubs commonly developed, as shown here, in the older locust plantings.

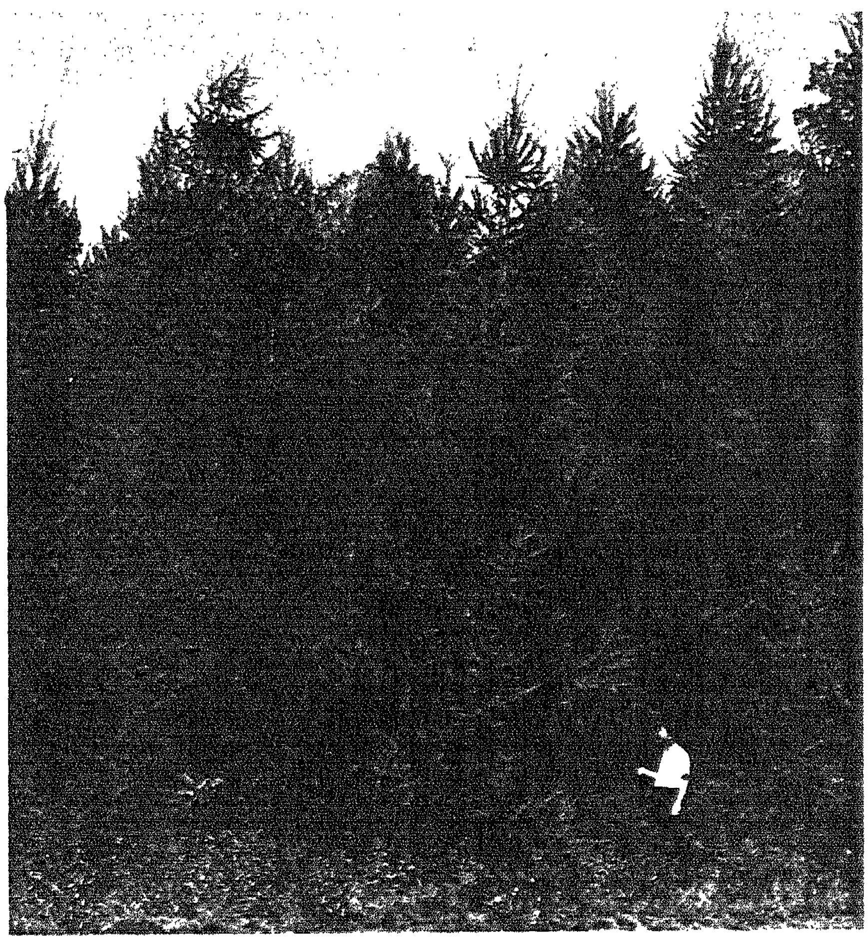
Black locust is a notoriously fast grower on mine spoils during its early years. Overall average height on our plots at 12 years was 30.1 feet. Growth was nearly the same on spoil types I and II, but was considerably poorer in the one plot on type III. Growth, like survival, increased with increasing pH. Grading and slope position did not exert much effect.

Conifers

Measurements of 10- to 18-year-old conifers were taken on 158 trees, representing 8 species. Tree age, average height, and diameter by small species groups or plots, and associated spoil characteristics, are shown in table 8. These miscellaneous small samples of trees growing under a diversity of spoil conditions obviously are an inadequate base for firm conclusions, but they do provide some evidence of how forest plantings develop beyond the establishment stage.

Most of the trees were developing normally and exhibited fair to good vigor. There had been no slow-down in growth up to the maximum ages observed. European and Japanese larches were the fastest growing coniferous species and they were growing about equally well (fig. 7). The somewhat poorer growth of the first

Figure 7.—Fifteen-year-old European larch plantation in Hanover Township, Pa., on graded spoil type II of pH 4.9. Survival was 95 percent.



group of Japanese larch (table 8) may be due to the coarse texture of the spoil material.

In general, height and diameter growth of jack, red, pitch, and Scotch pines were comparable (fig. 8 and fig. 9). The distinctly below-average growth of the first group of jack pine and the one group of Virginia pines possibly resulted from the low proportion of soil (particles less than 2 millimeters in diameter) in these particular spoil materials. The one planting of older white pine had made exceptionally good growth — 24.3 feet average height at 18 years. No particular feature of the site to account for this good growth was identified.

Figure 8.—Twelve-year-old Scotch pine plantation in the vicinity of Nanticoke, Pa. on ungraded spoil type III of pH 4.2. Survival was about 40 percent, average height 14 feet.

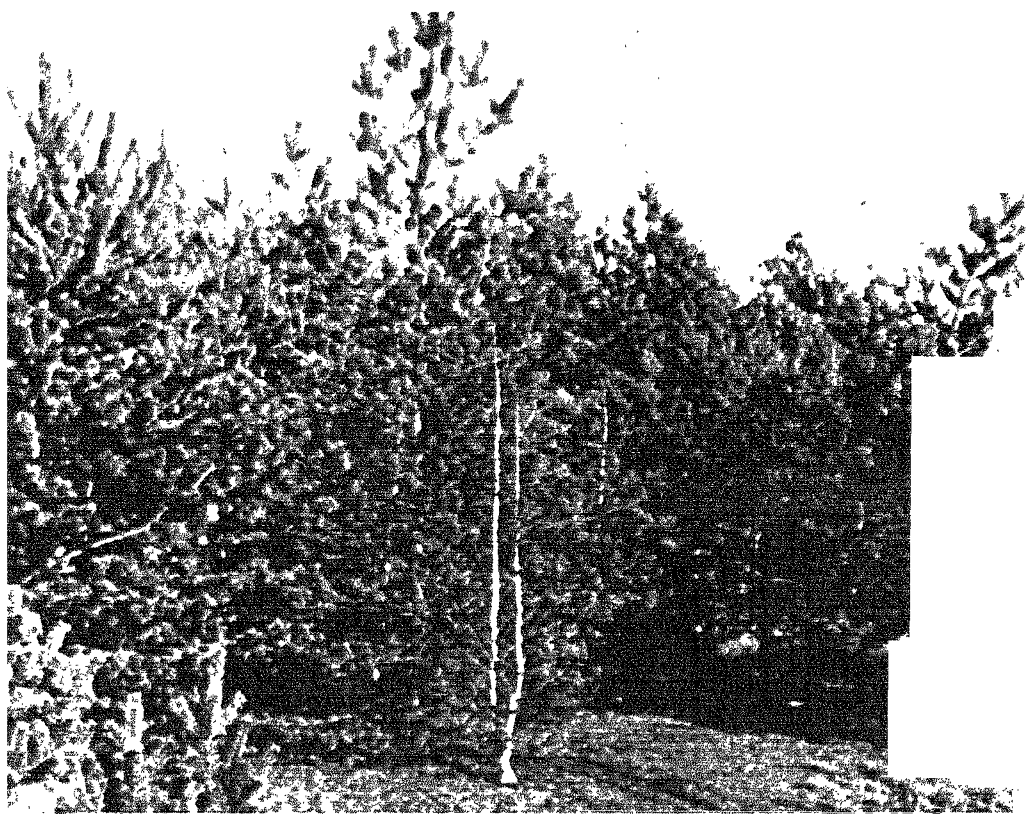


Figure 9.—Ten-year-old jack pine plantation in Wanamie, Pa., on graded spoil type IV.

Table 9.—*Suitability of various sites and conditions on strip-mine spoils for different tree species*[1]

Species	Spoil acidity		Spoil type and grading treatment[2]			Effect of grading on —		Remarks
	Observed range	Apparent optimum	Apparent optimum — Survival	Apparent optimum — Growth	To avoid	Survival	Growth	
	pH	*pH*						
Jack pine	3.8–6.5	4.0–6.0	III–G; IV–G	II; IV	IV–U	Variable	Slightly unfavorable	High mortality due to erosion
Red pine[3]	3.6–8.2	4.0–6.0	I–G; III–G	I; III–G	Heavy tex. spoils	No comparable data		High mortality due to erosion
White pine[3]	3.9–6.8	4.5–6.0	II–G; III–G	III	I–U; IV–U	No comparable data		High mortality due to erosion
Norway spruce	3.5–7.5	4.0–6.0	II–U; III–G	III	I–G; IV–U	Very favorable	Detrimental	Slow early growth
White spruce	3.7–7.8	5.0–6.0	III–G	III	I–G	Slightly favorable	Detrimental	Slow early growth
Japanese larch	3.0–7.0	4.0–5.0	I; II; III	II; III	IV; alkaline spoils	Slightly favorable	Detrimental	Species highly variable
European larch	3.6–7.1	5.0–6.0	II; IV	I–U; II; IV–G	I–G	Slightly favorable	Slightly unfavorable	Species highly variable
Black locust	3.7–6.4	5.0–6.5	II; III	II	Extreme acid I	Slightly favorable	Variable	

[1] Estimates based on both the 7-year and older plantings in this study, and on other plantings observed on mine-spoils throughout the Anthracite Region.

[2] Spoil type shown by Roman numeral; G = graded; U = ungraded.

[3] Species observed only on graded areas.

Discussion and Recommendations

Although this study yielded the most comprehensive and detailed data ever assembled on forest tree plantings as related to strip-mine spoil characteristics in the Anthracite Region, it was nevertheless only a survey of existing plantings that had not been planned and laid out for experimental purposes. Such standard experimental arrangements as replicated plots of each of several species of the same age on each of several specified site conditions simply could not be found. So there are many gaps in the record. Moreover, a number of seeming inconsistencies in tree performance that could not be explained were observed. The causes no doubt lie in obscure differences in the physical and chemical make-up of the spoil material that we did not recognize in this first study.

What we have at this point is a general picture of how plantings of various species on the average strip-mine spoil will develop during the first 7 years, plus some limited evidence on the development of these plantings up to 15 or 20 years of age. We have some ideas about the relative suitability of different spoil types and sites for tree growth, and about the adaptability of different species to these spoil types and sites. But we cannot predict with much precision just how well a given species will grow at a specific location. However, certain generalizations can be made:

- Black locust will provide cover in less time than any other species that has been tried, and it will grow reasonably well on practically all spoils that are capable of supporting any kind of plant growth. Being deciduous, it is not so desirable as evergreens for year-round screen and cover purposes.
- Red pine is the most generally reliable evergreen. It seems capable of surviving and making at least fair growth in practically all situations that will support plants. Jack pine may be considered second to red pine as an evergreen of all-round utility.
- The larches, though adapted to a wide range of spoil sites, are more variable and erratic in performance than red pine,

and they are deciduous. However, they usually will grow considerably faster than red pine. Of the two common species, Japanese larch should be chosen for the more acid sites and European larch for the mildly acid to neutral sites.

The spruces will survive adequately in most situations, but their early growth is slower than that of most other species, and their capacity for good growth later remains to be demonstrated. The spruces would be a poor choice where the time required to attain a given size is important.

A major objective of this study was to prepare a preliminary planting guide for use in tree planting projects in the Pennsylvania Anthracite Region. But because of the deficiencies in our data, a true guide — one that would specify particular species for particular site situations and conditions — cannot be prepared as yet. However, we do have a number of useful observations on the suitability of various site situations for different species. These observations are given in table 9. Although the table is based primarily on the study plots, observations on other plantings on mine spoils also were considered. The table is designed mainly to identify, for each species, the situations that seem to be distinctly more favorable, and those that are distinctly less favorable than the average run of mine spoil sites. Situations that are not named can be assumed to be suitable — neither particularly good nor particularly bad — for the species under consideration. Table 9, in conjunction with the preceding general statements on black locust, red and jack pines, larches, and spruces, should serve as a tentative planting guide until better information becomes available.

Another of the listed objectives of this study was to identify the gaps in our knowledge of ways to revegetate strip-mine spoils and suggest problems most in need of further research. The survey results have clearly demonstrated that several tree species will survive and grow reasonably well on many spoil sites. But the survey also has clearly demonstrated that we do not have really reliable information about comparative performance of the different species on the same sites, or about what are the most influential site factors. A properly designed planting experiment to provide reliable comparative data on the performance of different species on different site situations seemed clearly to rank high in priority, and such an experiment was begun in the spring of 1963.

Summary

A survey type of study was conducted in 1962 and in 1963 to evaluate the performance of existing forest-tree plantings of several species on strip-mine spoils of the Anthracite Region. The spoils were classified into four types based on the predominant parent material. Tree measurements 7 years after planting, together with pH and certain physical characteristics of the spoil, were obtained from 198 sample plots. All known plantations of suitable age throughout all four anthracite coal fields were sampled. From the results of the study the following generalizations may be stated:

- Overall average survival of all species was adequate (in the range of 40 to 60 percent), provided no disturbance had occurred after planting.
- Height growth of trees planted on the spoils was generally comparable to growth on natural soils of average productivity. Red pine, for instance, averaged 4.1 feet tall 7 years after planting, and the larches averaged 5 to 6 feet.
- No extensive conditions that would preclude tree growth were observed. The performance of existing plantings indicates that a tree cover of some sort can be re-established on practically all anthracite strip-mine spoil areas.
- Survival and growth of most of the species studied varied with such site characteristics as spoil type, soil texture, pH, grading history, and slope position. The trend and the magnitude of the effects of these factors differed somewhat among species, but we do not now have suitable data to define the precise relationships.

A preliminary guide for forest tree planting on anthracite spoils has been prepared on the basis of the present data. It is weak in many respects, and will require refinement by further research before species can be recommended for different mine-spoil sites with assurance of optimum survival and growth.

A high-priority research need is to determine the comparative

performance of different tree species on different mine-spoil sites. This will require properly designed experimental plantings. Research of this sort was begun in the spring of 1963.

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