FORESTATION of STRIP-MINED LAND in the Central States

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of STRIP- MINED LAND

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FOREWORD

Land recently strip mined for coal is not a pretty sight, nor is it producing anything. This apparent desolation need not be permanent, however, because it is possible to reclaim most of this land—improve its appearance and restore it to productivity.

One of the best ways to do this is to establish forest cover. However, because the artificially produced site conditions on mine spoil banks are so unlike most natural planting sites, commonly accepted principles and practices of artificial forestation are not always successful. In fact, it was because the coal mining companies ran into so many new problems in getting plantations started on their strip-mined land that public forest research agencies were called upon to tackle the problem.

Personnel at the Central States Forest Experiment Station have been engaged in this field of research since 1937. All this work was done in nine midwestern States—Arkansas, Illinois, Indiana, Iowa, Kansas, Kentucky, Missouri, Ohio, and Oklahoma. Although many of the principles and procedures developed apply to forestation work on any land stripped for coal, differences in topography, climate, and vegetation in neighboring States may limit the application of some of the results reported in this publication.

As research results became available, they were immediately made known in publications (*29*) and progress reports, and by field demonstrations. There is perhaps no better example of quick acceptance of forestry research than the speed with which these results were adopted by the mining companies in reclaiming their land. The early application of research results in this field reflects the need and public demand for information of this kind.

This publication summarizes the knowledge gained during the past two decades and is intended to serve as a guide for technicians engaged in forestation of strip-mined land. It attempts to answer the question: Where, when, and how should tree planting be done on such land? Chief emphasis is placed on a detailed discussion of site conditions that affect forestation on strip-mined land. After that, the planting operation itself is described.

CONTENTS

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Forestation of Strip-Mined Land in the Central States

By G. A. Limstrom

Strip mining for coal has become big business in the United States. When this country entered the Second World War, coal mined by stripping amounted to about 11 percent of the total production (*53*).[1] During the following 7 years this percentage more than doubled. In the Central States region alone, the total area of land strip mined for coal was nearly 200,000 acres through 1947, the last year for which reliable estimates for the region as a whole are available (fig. 1) (*25*). There is no evidence that stripping has declined during the last decade. In some States the total area strip mined has more than doubled since 1947. Overall, the area affected is insignificant. In some localities, however, where the amount of stripped land may exceed 5 percent of the total area in a county, the restoration of stripped land to some productive use has, in turn, become big business.

[1] Italic numbers in parentheses refer to Literature Cited, page 67.

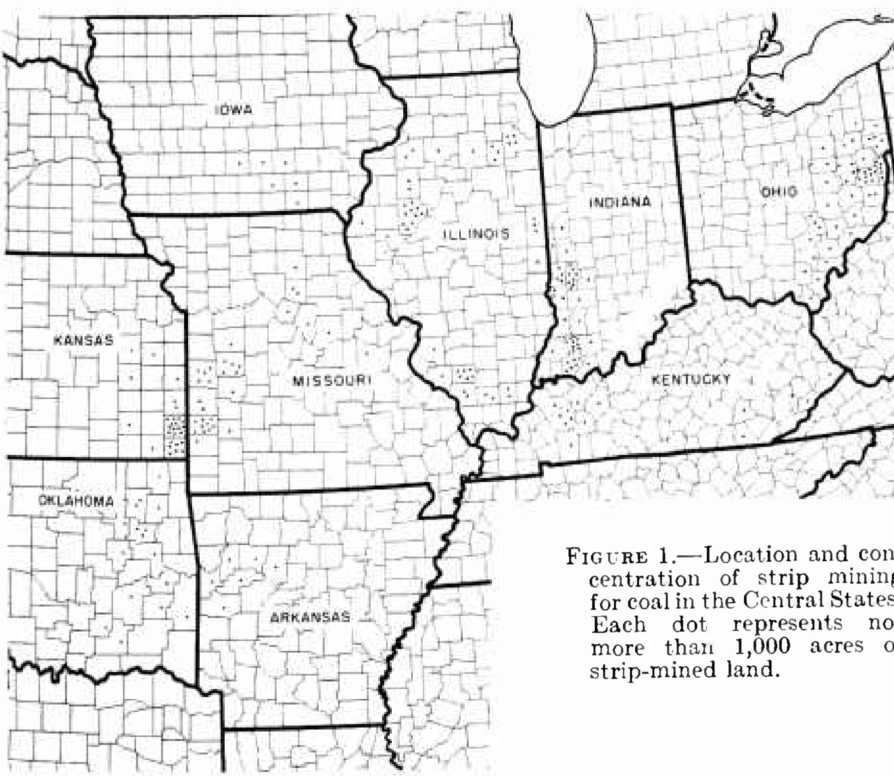

FIGURE 1.—Location and concentration of strip mining for coal in the Central States. Each dot represents not more than 1,000 acres of strip-mined land.

By 1947 more than 33,000 acres of stripped land supported well-established forest plantations. Since that time the tempo of reclamation has kept pace with the increase in strip mining. In some States a high percentage of planting stock produced in public nurseries is allocated for the forestation of strip-mined land (*43*).

Tree planting is not the only way to reclaim strip-mined land; in some States much of the total strip-mined area is used for pasture. But tree planting does combine several benefits that some of the other methods do not produce. First, of course, trees will eventually produce a salable crop, whether it be in the form of Christmas trees, posts, pulpwood, or sawtimber. Not much is known about the yields of the larger timber products, but, as will be shown later, evidence so far indicates that trees planted on strip-mined land often grow as fast as those planted on other land, and sometimes faster. Then there is the well-recognized capacity of some tree species to stabilize slopes. On some strip-mined land no other vegetational cover is as effective a watershed management tool as trees. And finally, forested strip-mined land makes good parks and wildlife habitat, which in turn help to fill the ever-increasing demand for outdoor recreational facilities. The innumerable ponds and small lakes formed by simple impoundment procedures in many parts of the region have proved to be excellent water for game fish (fig. 2) (*44*). Along these watercourses many good camping and picnic grounds have been established.

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FIGURE 2.—Tree planting can help convert strip mines to attractive recreation areas such as this one.

SITE CONDITIONS AFFECTING FORESTATION OF STRIP-MINED LAND

Site conditions on strip-mined land are unique; they are so different from those on other land surfaces that a separate classification of factors influencing tree growth is needed. The big difference between site conditions for growing trees on strip-mined land and on undisturbed land lies in the differences of the rooting medium. On lands undisturbed by strip mining, the soil is an organized natural body resulting from the modification of parent materials near the earth's surface; the rooting medium on strip-mined land is an unorganized mass of material derived from any or all strata between the earth's surface and the coal seam mined. Strip-mined surfaces differ also from land surfaces made barren by erosion and toxic gases; in the latter situations the underlying strata have not been moved while in the strip-mining operation they have been overturned and mixed. Depending on the number and kinds of strata overturned, bank surfaces are sometimes rather uniform in character, but great variation even within small areas is more common. To account for the behavior of tree growth on strip-mined land, an understanding of the important site factors is essential.

PHYSICAL CHARACTERISTICS

The conditions that influence aeration and moisture of bank materials are the most important physical characteristics affecting plantation establishment and growth. These include the amount of stone present, and the texture and aggregation of the soil. (In this text, "soil" includes only mineral particles less than 2 millimeters in diameter; particles smaller than 2 millimeters are sands, silts, or clays; particles larger than this are called "stones.")

Amount of Stone and Soil

The relative amounts of stone and soil on the surface of strip-mined land have a bearing on readiness for planting, method of planting, and planting success. Drainage would be so rapid and water retention so low on banks composed entirely of loose stones that few planted trees would survive. Because of natural weathering processes and the common occurrence of some soil in the overburden, this condition seldom exists.

The minimum percentage of soil needed for planting varies from one kind of bank to another. Only a small amount of soil, however, is needed. Good initial survival on banks with only 20 percent soil has been reported by Bramble (*6*) and Clark (*13*). At least part of this success is attributed to moisture lodged in or adhering to stones—a factor which until recently has been ignored in soil moisture studies. In a recent study of the moisture content of small stone in several Piedmont soil profiles, Coile (*14*) found that the water supply in stones available to plants varied with the size, concentration, and composition of stones present, and that stones contributed to the water supply available to plants.

513374 O—60——2

That water held by stones may account for good survival on some banks with a high percentage of stone is borne out in observations by Stiver (*48*). He observed free water between the laminae of shale particles even during the dry month of August. "On the dull black shales, which are very loose in structure, free water has been found in a dry August at a 3-inch depth. The water remains in the shale because there is not a continuous water column in any direction, the large pores in such a loose structure having no attraction for the water."

The relative amounts of stone on bank surfaces have an important bearing on the methods of planting that can be used. Often this factor alone will determine whether an area can be planted by mattock, bar, or machine methods.

Texture

Texture—usually recorded as the relative amounts of sand, silt, and clay in a soil—influences moisture and aeration conditions on strip-mined land to about the same degree as in undisturbed soils. The amount of stone on bank surfaces changes rapidly from year to year because of weathering and erosion. As a result, the relative amount of soil—and to some extent its texture—changes during the rotation period of a timber crop. So in planning the reclamation of stripped land by forest planting, only three broad textural classes need be recognized:

1. *Sand.*—Soil containing less than 20 percent silt and clay. The stones usually associated with this class are sandstones and sandy shales.
2. *Loam.*—Soil containing less than 80 percent sand and less than 30 percent clay. Most of the stones associated with this class are siltstones and silty shales.
3. *Clay.*—Soil containing more than 30 percent clay. Most of the stones associated with this class are limestones, clay shales, and marl.

These classes can be easily recognized in the field. Field classification can be verified by mechanical analysis (*4*, *57*). Because the proportion of stone has an important effect on drainage and aeration, the soil textural class may be modified by adding "Stony", "Shaly", or "Gravelly" wherever appropriate.

The various responses of trees on banks of different soil texture are evident at an early age. Second-year survival and mean total heights of trees planted on three strip-mined areas of different soil textures show that, in general, early survival and growth are better on the finer textured soils than on the sands (table 1). Excessive drainage, resulting in droughty conditions, perhaps accounts for most of the generally poorer survival and growth on the sandy area. The clay soil, on the other hand, would be poorly drained but for the fact that it contains 25 to 35 percent stones. This tends to make drainage and moisture conditions much more favorable for tree growth than in soils of this heavy texture without stones on undisturbed land. For some species, however, such as the pines, green ash, black locust, cottonwood, and silver maple, early development on sandy areas appears satisfactory.

TABLE 1.—*Second-year survival and total height of trees planted on strip-mined banks of three different soil textures*

Species	Soil texture					
	Sand		Stony loam		Stony clay	
	Survival	Height	Survival	Height	Survival	Height
	Percent	*Feet*	*Percent*	*Feet*	*Percent*	*Feet*
Eastern redcedar	22	0.9	74	0.6	59	0.9
Jack pine	59	.7	84	.8	94	.9
Red pine	61	.4	70	.5	94	.5
Eastern white pine	55	.5	59	.5	81	.5
Pitch pine	47	.4	97	.6	84	.7
Green ash	91	1.0	94	.9	97	1.5
Black locust	85	4.6	98	4.5	95	(1)
Black walnut seed	21	.9	79	.7	53	.9
Eastern cottonwood	71	3.0	64	2.2	70	2.6
Silver maple	80	2.4	79	1.5	93	2.0
Black walnut	1	.7	36	.9	21	.9

[1] Tops of all trees partly dead.

Aggregation

In strip mining, the material overlying the coal is broken up into fragments of various sizes and shapes. Piled on the banks more or less at random, these fragments may, during the weathering process, distintegrate into small aggregates or form larger ones. The degree of aggregation and the stability of the aggregates have an important effect on the water movement, erodibility, and productivity of strip-mined land. The kind and amount of aggregation in strip-mine bank surfaces depend a great deal upon the structure and consistence of the original strata occurring in the overburden before stripping.

As pointed out by Baver (*3*), there have been a number of definitions and classifications of soil structure, all based on different points of view and intended methods of application. Regarded usually as denoting the arrangement of soil particles, the structure of soil is often described by such terms as "granular," "cubelike," "fragmental," "platy," "blocky," and "single-grained."

Soil consistence includes such properties as resistance to compression and shear, friability, plasticity, and stickiness (*3*). Whereas structure refers to the degree of aggregation of soil particles, consistence denotes the force by which soil particles are held together. Soil consistence is often described by such terms as "loose," "compact," "friable," "crumbly," "plastic," "sticky," and "cemented." For field classification of consistence, the procedure outlined in the Soil Survey Manual (*46*) appears practicable. It is based on the resistance to change in shape under varying degrees of applied stress when moistened enough to be at or slightly above field capacity. When it can be rolled to form a rod or wire of soil and much pressure is required before deformation takes place, the soil is said to be very plastic; if no rod is formable, it is nonplastic.

Mineralogical analyses may also be helpful. Soils made up mainly from quartz and feldspar are apt to be nonplastic, whereas those composed mainly of kaolinite, talc, muscovite, or biotite will most likely be plastic (*3*). The montmorillonite clays are also highly plastic.

Only a few plasticity tests of bank materials have been made up to the present time. Those that have been made disclose such close correlation with texture that a separate consideration of this factor in site evaluations for tree planting on strip-mined land does not appear necessary. The significance of structure and consistence in the productivity of strip-mined land has, moreover, not been completely evaluated. For the present, then, the importance of these two soil properties is recognized only by their relation to the aggregation of bank materials.

Only two types of aggregation, rather easily identified, are considered pertinent in classifying strip-mined land for tree planting:

1. *Loose bank materials.*—When holes are dug with a spade or mattock, the excavated material falls into a loose, unconsolidated pile, either as individual (single-grained) mineral particles or as aggregates usually smaller than 1 inch in diameter (fig. 3). If large stones are present, little or no soil adheres to them. Holes are easily dug with a spade. Footprints are clearly defined. Valleys become U-shaped in a year or so (fig. 4, *A*).

2. *Compact bank materials.*—Excavated material falls into clods or aggregates larger than 1 inch in diameter. If large stones are present, soil particles adhere to them. Much pressure is needed to insert the spade into the ground; in fact, a pick or mattock is almost always needed for digging holes. Footprints are scarcely visible except when wet. Valleys remain V-shaped for many years (fig. 4, *B*).

The effects of loose and compact bank surfaces on tree survival and growth are difficult to separate from the effects of other site factors; the combined effects of many of these factors are discussed in the section on "The Net Effect," page 36.

Classification

Strip-mined banks are classified into bank types as follows: (1) sands, (2) loams, and (3) clays (*25*). In each bank type, classes may be differentiated by the degree of aggregation, that is, loose or compact. In many cases it is useful to recognize different phases of stoniness. These various criteria, already discussed, for classifying the physical characteristics of strip-mined banks are combined to form descriptive terms considered useful in appraising such land for tree planting. Some of the most common of these terms are sands, stony sands, loose shaly loams, compact loams, compact stony clays, loose shaly clays, and compact clays.

Chemical Conditions

The acidity or alkalinity of bank materials is an important site condition to consider in reclaiming strip-mined land. It is, in fact, very often the limiting factor for plant growth. In making site

F-485116, 485115

Figure 3.—Different kinds of aggregation: *A*, Loose, shaly clay, easily dug with ordinary garden trowel; *B*, compact, stony clay, difficult to dig even with hoes and mattocks. Note large clods in *B*.

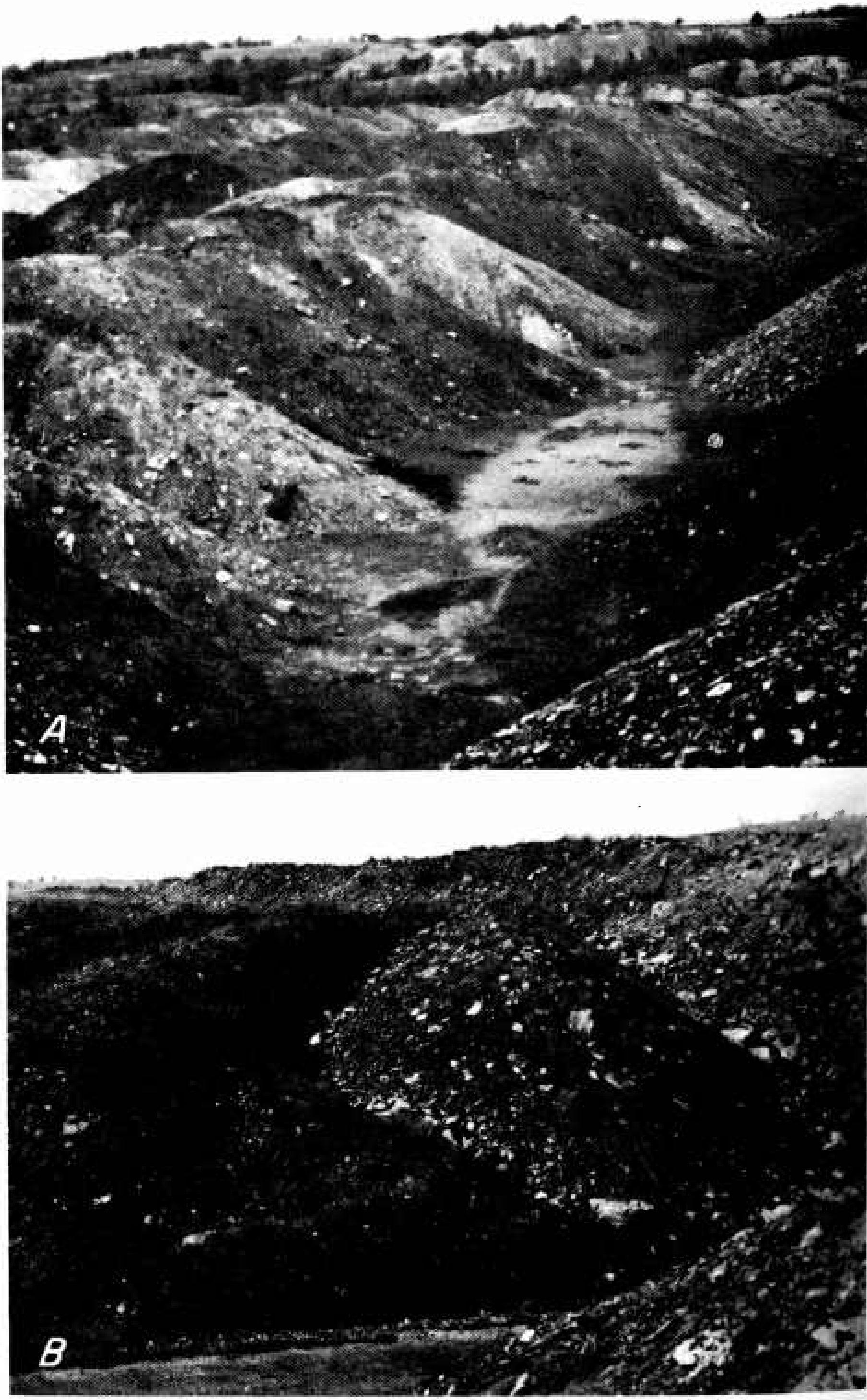

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FIGURE 4.—*A*, Loose, shaly, clay banks have developed U-shaped bottoms in less than 2 years; *B*, compact, stony clay banks retain their V-shape for many years.

appraisals on strip-mined lands in the region, the most practical method for determining the range of acidity or alkalinity is by taking a number of pH determinations (*32*). A pH of 4.0 or less is considered very strongly acid and generally indicates conditions lethal to most plants. A pH of 4.0 to 5.0 is strongly acid; 5.1 to 6.9 is moderately to mildly acid; 7.0 is neutral. A pH higher than 7.0 is alkaline (usually calcareous in the Central States).

Survival and Growth

Data are lacking on maximum and minimum pH values for the survival and growth of a large number of tree species (*47*). However, Stiver (*48*) observed that Virginia pine on strip-mined land in Indiana survived in media having a pH of 3.5. On three different strip-mined areas in Ohio, the total height of 2-year-old black locust was almost twice as great on surfaces where pH ranged from 6.8 to 7.8 as on surfaces where the range was from 3.0 to 5.5 (*32*). Stunted growth of white pine, white ash, and yellow-poplar has been observed in the transition zone between toxic areas having pH values below 4.0 and areas of good growth having pH 4.5 and higher (fig. 5; table 2).

Soil acidity in itself does not, within limits, influence plant growth. Rather, it influences the availability of soil nutrients, chiefly in affecting the solubility of minerals (*24*) for absorption by plant roots, and in affecting the occurrence and abundance of soil micro-

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FIGURE 5.—Ten-year-old white pine plantation on strip-mined land in Ohio. Barren area in right foreground (pH less than 3.8) was planted at the same time as the remainder of the plot. Note stunted growth of pine in transition zone between the highly acid area and the plantable area in background where pH is generally more than 4.5.

TABLE 2.—*Effect of pH on height of 10-year-old planted trees on graded banks in Ohio*

Species	pH 3.0–4.1	pH 4.2–4.6	pH 4.7–5.2
	Feet	*Feet*	*Feet*
Yellow-poplar	5. 3	14. 0	
White ash	7. 2		11. 5
Eastern white pine		2. 6	6. 7

organisms. For more specific information, however, it is necessary to turn to studies on agricultural plants. In controlled laboratory experiments, Arnon and Johnson (*2*) tested the development of tomatoes, lettuce, and Bermuda grass plants in media ranging in pH from 3.0 to 9.0 with all nutrients except sulfates at a constant concentration. They drew two principal conclusions from these experiments: "First, that fatal or profoundly adverse effects of external reaction are encountered only at extremes of acidity and alkalinity (pH 3.0 and 9.0); and second, that with certain reservations, fluctuations in hydrogen ion concentration *per se*, within the relatively wide range of pH between 4.0 and 8.0, are not inimical to the welfare of the plants so far studied." At pH 3.0 the plants were unable to absorb calcium and phosphate, and at pH 9.0 phosphate absorption was drastically curtailed. In the pH range from 4.0 to 8.0 good growth was possible only when special safeguards were taken to assure a good supply of nutrients.

Many kinds of bacteria, particularly those known to be nitrogen-fixing, thrive in soil with pH values greater than 5.5. Some nitrification, however, takes place below a pH of 5.5. Certain species of fungi, for example, "are able to effect those enzymic transfers" in media with lower pH values (*36*). Sulfur-oxidizing bacteria can survive in media of extremely high acidity.

Even though acidity has an important effect on the relative amounts of available elements, specific information on the optimum range for each species is lacking. Much research in this field of study is needed (*55*).

The pH determination is, however, a good indicator of several forms of toxicity. In strongly acid soils, capable of dissolving compounds of sulfur, iron, aluminum, and manganese, a plant may absorb so much of these substances that it may be injured or die. On strip-mined land most of the mortality attributed to toxicity is associated with high concentrations of sulfuric acid in the bank materials. The most common source of the sulfuric acid on stripped land is iron sulfide, which occurs chiefly as pyrite in the coal and in certain rocks making up the overburden most commonly in the roof coal, carbonaceous shales, and sandstone. As stripping proceeds, some of these sulfides are exposed to air and water and, upon oxidation in the presence of oxygen and water, sulfuric acid is formed.

Micro-organisms, found even in banks devoid of vegetation (*56*), no doubt influence the extent and duration of toxic materials on strip-mined land. Oxidation processes are most likely accelerated by sulfur-oxidizing bacteria. Reduction of the acid to hydrogen sulfide by sulfur-reducing bacteria, on the other hand, may also occur.

The strongly acid surfaces on stripped areas appear as dark, moist, and somewhat greasy-appearing spots and are most easily observed during warm, dry weather (fig. 6). The relatively high moisture content of these spots is due mostly to hygroscopic action of the acid. The extent and duration of strongly acid conditions on bank surfaces depend on the amount of sulfur-bearing rocks present as well as many interacting forces. Weathering, leaching, and runoff gradually reduce the concentration of acid on bank surfaces. However, on some erosive areas, the continual exposing of unoxidized material tends to prolong conditions of high acidity.

All the factors that tend to reduce acidity of bank surfaces are not yet known; such factors as climate, topography, the form of compounds in which the sulfides occur and their concentration, and the activity of soil micro-organisms are no doubt important. From four tests of highly acid bank surfaces in West Virginia, Tyner and Smith (*51*) reported that reductions of total sulfur content varied from about 25 to 50 percent in 1 year. If the same rates of reduction continue, they estimated that in 3 to 5 years these surfaces would support vegetation similar to adjacent bank surfaces with pH values varying from 4.6 to 5.6. These authors have, on the other hand, reported highly acid conditions on other bank surfaces more than 20 years old, with only a remote probability of vegetation developing unless limed (*52*).

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FIGURE 6.—A toxic, strip-mined area. The highly acid areas are dark, moist, and "greasy" in appearance.

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Field Tests and Classification

Acidity conditions may vary greatly on some stripped areas; the pH may, in fact, vary from 3.0 to 7.5 in spots only a foot apart. In forestation practice, however, only the predominant pH range for a given area should be considered. This can be determined by making a number of acidity tests, the number to be made depending on the size of the area, the uniformity of acidity conditions, and the degree of accuracy desired. Five classes of acidity are generally recognized (*25*):

1. *Toxic.*—More than 75 percent of the area with pH values less than 4.0.
2. *Marginal.*—50–75 percent of the area with pH values less than 4.0.
3. *Acid.*—More than 50 percent of the area with pH values from 4.0 to 6.9.
4. *Calcareous.*—More than 50 percent of the area with pH values of 7.0 or above.
5. *Mixed.*—Acidity values so varied that the area cannot be classified as toxic, marginal, acid, or calcareous.

Toxic areas are considered nonplantable; planting on marginal sites is considered desirable mainly for soil and landscape improvement. Banks classified as acid, calcareous, or mixed are plantable.

Marked increases in acidity have been observed on some mine banks over a number of years after stripping (*18*). This has been attributed to the presence of many hard, slowly weathering rocks containing a high percentage of sulfides. If acidity tests within a year after stripping disclose doubt of the plantability of the area, tests for sulfides should also be made (*42*) (see p. 72). As a general rule, however, acidity conditions improve on bank surfaces with the passing of time. Some stripped areas in Ohio, for example, have changed from "toxic" to "acid" in the relatively short span of 8 years.

Nutrient Availability

Although the nutrient requirements for many agricultural crops are well known, the relation of soil nutrients to site quality in forestry is still rather obscure. Evidence to date indicates that nutrient requirements for tree growth are generally much lower than for cultivated crops and that the requirements for conifers are usually less than for hardwoods (*35*). Nevertheless, nutrient deficiencies for some species do occur often enough to warrant attention to them.

Nutrition studies have pointed out the various requirements of a few species for each element. Heiberg (*22*) has shown the disastrous effects of potash deficiencies on the growth of certain conifers; Mitchell and Chandler (*41*) and Finn (*20*) have correlated growth of a number of hardwoods with varying amounts of foliar nitrogen, phosphorus, potassium, calcium, and other elements.

Recent analyses of samples taken from strip-mined land in the Central States reveal that amounts of potentially available phosphorus and potash may differ (*21, 30, 45, 48*). But in general the amounts available have been greater than those found on adjacent unmined land. Boron, for example, one of the so-called minor elements but necessary to plant growth, was found in "medium" and "high" amounts on stripped land in Illinois (*49*).

Although nitrogen is generally lacking in freshly mined material, in a few years the quantity available increases enough to meet the requirements of many trees. This increase comes mainly from rainfall and from leguminous plants (*12*). On 3- to 5-year-old banks planted to black locust, for example, foliar analyses conducted by Finn (*20*) disclosed available nitrogen as well as phosphorus, potassium, and calcium in amounts comparable to those generally found on other land.

On a number of acid strip-mined areas low in phosphorus, Stiver (*48*) tested the effects of adding various amounts of lime and rock phosphate on spots planted to Virginia pine. No discernible effects on survival or growth were observed. In other plots on the same banks, where an abnormal yellow cast on 2-year-old Virginia pine was observed, nitrogen fertilizer was used. The applications (80 pounds of ammonium nitrate per acre) were made on May 1 and by June 1 the yellow cast had disappeared. Moreover, growth in diameter of the new shoots was 2 to 3 times greater on the treated plots than on the untreated.

Site quality for a number of tree species has been found to be correlated with certain physical characteristics of the soil. The preceding section showed that nutrient availability is affected by acidity. It is apparent, then, that the main effects of soil nutrients in promoting tree survival and growth are associated with physical characteristics of the soil and its acidity. For these reasons, the evaluation of nutrient availability *per se* in the general classification of strip-mined land for forest planting is not yet considered advisable or necessary at this time. As research progresses, however, there is little doubt that nutrient deficiencies will be found to be a limiting factor on some sites.

Topography

Topography influences survival and growth largely through its effects on soil moisture, soil depth, light, temperature, erosion, and protection from wind. Some of these effects in turn are affected by physical characteristics of the bank materials.

Soil moisture studies on stripped land in Ohio and Kansas (*28*) disclosed that, except for periods of prolonged drought, there is only a little difference in moisture conditions between slopes of different exposures. Although during dry periods in late summer, slopes facing south and west tended to be drier than those facing north and east, moisture conditions during the period when most of the height growth occurs (May and June) were about the same on all aspects. Significantly better moisture conditions prevailed on the lower slopes than on the upper, especially on the coarse, somewhat sandy banks.

Results from more than 30 planting experiments show little or no differences in survival among aspects and between upper and lower slopes. In Illinois slightly better survival of hardwoods was found on lower slopes and northern aspects than on upper slopes and southern aspects, but the differences were not great enough to have any practical application (*30*). The conifers were similarly influenced by aspect, but their position on the slope had no effect on their survival.

Furthermore, all these experiments show rather conclusively that exposure (aspect) has little effect on height growth. This is perhaps due to the fact that severe droughts rarely occur in the region during the period of greatest growth in early summer. Differences in height growth of trees planted on upper and lower slopes have on the other hand been highly significant on some banks and not significant on others. The erratic behavior of tree growth on upper and lower slopes shows that factors other than position on slope also influence growth; the most important of these other factors are erosion, texture, and aggregation. Striking similarity in total heights for different exposures on the one hand and erratic response among different topographic positions on the other, were brought out in studies (*13*) of 14 species planted on 11 strip-mined areas in Kansas and Missouri (table 3).

TABLE 3.—*Six-year height growth of 14 species by aspect and topographic position on strip-mined areas in Kansas and Missouri* (*13*)

Species	Topographic position		Aspect	
	Ridgetops	Bottoms	North and east	South and west
	Feet	*Feet*	*Feet*	*Feet*
Black locust	14. 2	21. 1	17. 5	17. 8
Virginia pine	5. 7	5. 5	5. 9	5. 9
Loblolly pine	5. 5	4. 2	7. 0	5. 8
Green ash	5. 4	5. 9	5. 7	6. 2
Eastern redcedar	4. 6	5. 4	5. 0	5. 1
Pitch pine	4. 2	3. 9	5. 4	4. 4
Bur oak	3. 6	3. 8	4. 3	4. 3
Black cherry	3. 9	5. 3	4. 2	4. 3
Jack pine	3. 1	4. 7	3. 9	3. 7
Black walnut seed	2. 9	3. 0	2. 7	2. 8
Bur oak seed	2. 8	2. 0	3. 3	3. 0
Ponderosa pine	2. 1	1. 8	2. 7	2. 7
Sycamore [1]	6. 1	5. 5	7. 0	7. 9
Shortleaf pine [1]	3. 2	4. 1	4. 2	3. 8

[1] Planted in 1948, 5-year growth.

A survey of older plantations (15–25 years) in Indiana confirmed the results obtained in the younger plantations on the experimental areas (*17*). In this survey it was also found that the total height of the banks (relief) had a significant effect on the growth of trees planted on the upper slopes and ridgetops, and that the differences were greater on coarse, sandy soils than on silty, clayey soils.

From these results it appears best to classify topography of ungraded banks for tree planting simply on the basis of relief. Only two relief classes need to be recognized: (1) Upper slopes, which include the ridgetop and the upper two-thirds of the slopes; (2) lower slopes, which include the lower third of the slopes and the bottoms between slopes. If the average relief is less than 15 feet, the entire area may be classed as lower slope. The bottoms between ridges are, as a rule, slightly better sites than the lower slopes, but the amount of area in bottoms is generally so insignificant that a separate classification of bottoms seem impractical.

On some of the poorly drained, U-shaped bottoms that are covered intermittently by water, survival and growth have been very poor (*13*). These bottoms, sometimes easily detected on old banks by a dense cover of cattails and other aquatic vegetation, could very well be omitted in planting (fig. 7).

Vegetation

Although most strip-mined areas to be planted are barren, vegetation does exist on some strip-mined land at the time of tree planting. This can be both beneficial and detrimental. If not too dense, natural vegetation helps protect seedlings from drying winds, improves soil conditions, and reduces losses from erosion. On the other hand, natural vegetation competes with planted trees for soil moisture and nutrients. Depending upon the species to be planted, natural vegetation may permit too little, too much, or just the right amount of light for good survival and growth. Its evaluation and control are therefore important aspects of reclamation planning.

In preplanting surveys two broad classes of vegetation are generally recognized: (1) *Ground cover*, which includes all weeds, grasses, shrubs, and tree seedlings; and (2) *crown cover*, which includes the larger trees. For tree planting on strip-mined land, only two classes of ground cover need to be recognized: (a) *Heavy*, which completely shades or overtops 50 percent or more of the planted seedlings during the first growing season; (b) *light*, which completely shades or overtops less than 50 percent of the planted seedlings during the first growing season. Three classes of crown cover should be considered: (a) *Light*, less than 10 percent of the ground shaded by overhead cover; (b) *moderate*, 10 to 75 percent of the ground shaded by overhead cover; (c) *heavy*, more than 75 percent of the ground shaded by overhead cover.

Mortality and growth on sites with heavy ground cover will vary with the density and character of the cover, weather conditions, and species planted (fig. 8). Dense cover also encourages high rodent and rabbit populations.

Two experimental areas in one locality in Illinois planted in 1947 serve as demonstrations of the effects of vegetation. One area supported a sparse, light ground cover, the other a dense, heavy cover of sweet clover. The average second-year survival of 17 species planted was 61 percent in the light cover and only 27 percent in the heavy cover. Ash and eastern redcedar were the only species tested that survived well under the dense clover. The other species planted in this test were black locust, cottonwood, yellow-poplar, loblolly pine, jack pine, black walnut seed, black walnut seedlings, eastern white pine, Osage-orange, red pine, shortleaf pine, silver maple, Virginia pine, pitch pine, and sweetgum.

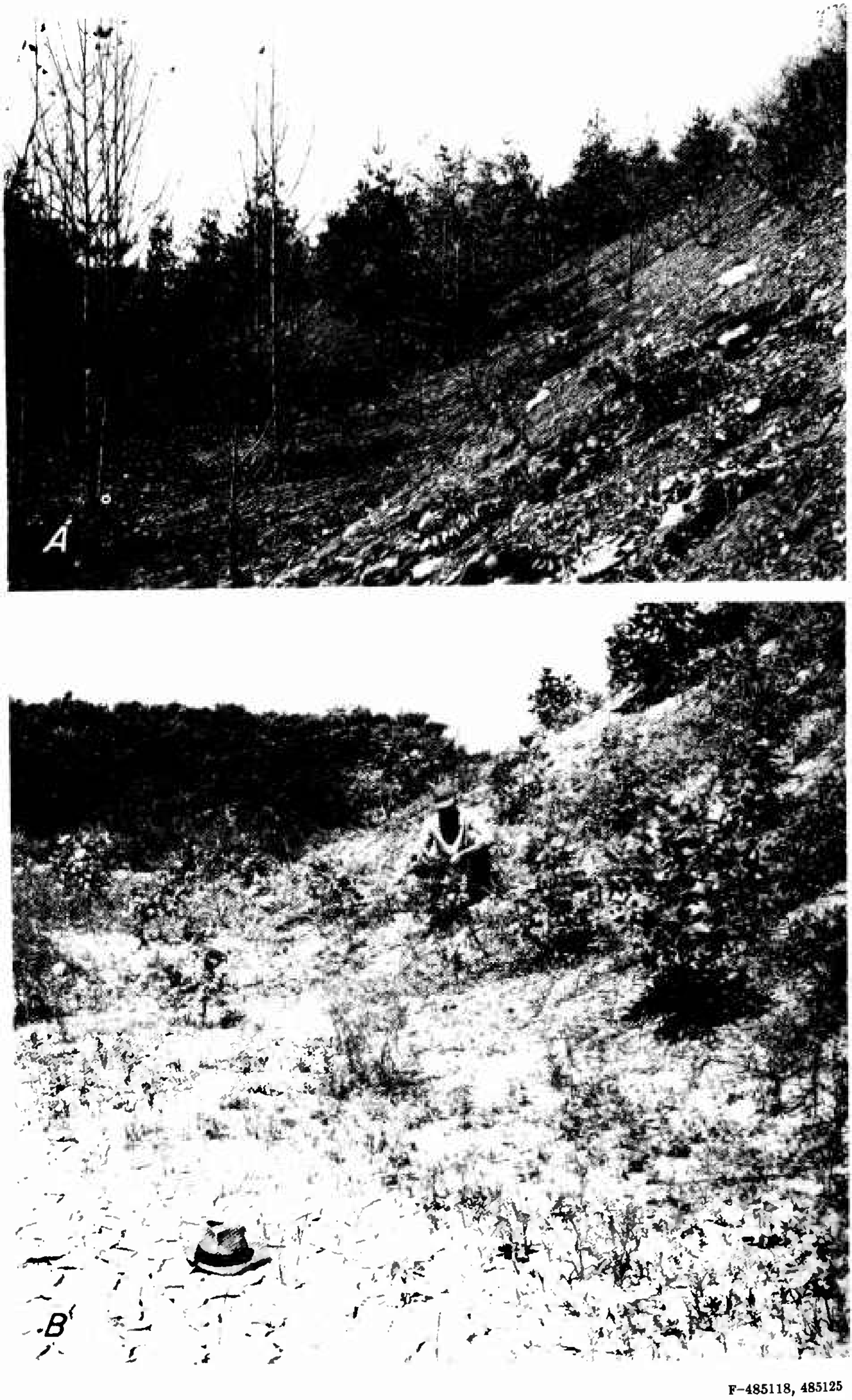

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FIGURE 7.—Yellow-poplar: *A*, On loose banks, growth is generally much faster in bottoms than on the slopes; *B*, on loose banks with poorly drained bottoms, growth is better on the slopes.

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FIGURE 8.—A dense stand of sweet clover has greatly retarded the growth of this 4-year-old Scotch pine.

The effect of crown cover on the survival and growth of underplanted trees likewise depends upon the character and density of crown cover and the species underplanted. Where the crown canopy is composed primarily of leguminous plants, such as black locust, these plants improve growing conditions by adding nitrogen to the soil. This is brought about by nitrogen-fixing bacteria associated with the root development of these species (*12*). A dense overhead cover of any species, on the other hand, has an adverse effect on the survival and growth of most species underplanted. The response to these environmental conditions varies according to the tolerance of the underplanted species to shade and to their nutrient requirements, particularly of nitrogen.

ORIGIN OF BANK "SITE"

Although it is important for the practitioner to be familiar with the various site conditions that influence the survival and growth of planted trees, it is equally important that he know how these conditions came about. Site conditions on strip-mined land depend in general upon four things: (1) Parent material of the surface layer, (2) methods of mining, (3) whether or not the banks were graded after mining, and (4) extent of erosion.

Parent Material

The parent material of soils developing on strip-mined land consists of one or more of the strata overturned in the mining operation. Although the surface of the banks may be a random mixture of many of these strata, usually materials from only one or two predominate. The future productivity of the land depends to a great extent upon which strata provide the materials. Each differs from the others in physical and chemical properties, and therefore contributes different characteristics to bank surfaces (tables 4 and 5). The important differences are in acidity, soil texture, structure, rates of weathering, erodibility, and the relative amounts of soil and stone.

Detailed physical and chemical analyses of individual strata in several high walls adjacent to some strip-mined land in Illinois were made by Thurn (*49*). His data indicate the wide variation in physical and chemical properties among different strata (table 6). The data presented in this table do not represent average stratigraphic and bank-surface conditions in the region. Variations of both are so great for each coal seam and locality that they cannot

Table 4.—*Comparison of high-wall strata and bank characteristics 2 years after stripping, Harrison County, Ohio*

HIGH WALL

(Exposed overburden in final cut adjacent to banks)

Strata (top to bottom)	Thickness	Acidity	Available phosphorus [1]	Available potash [2]
	Feet	*pH*		
Topsoil	1	5. 9	Low	Low.
Subsoil	3	5. 6	do	Do.
Shale, clayey	15	6. 6	Medium	Do.
Shale, carbonaceous	1	5. 8	do	Do.
Limestone	27		High	Do.
Shale	3	6. 8	Medium	Do.
Coal, shaly	1	5. 2	Low	Do.
Limestone	20			
Shale	6	7. 0	Low	Do.

BANK SURFACE (4 samples)

Texture	Acidity	Amount of stone [3]	Available phosphorus	Available potash
	pH	*Percent*		
Clay	6. 4	44. 2	High	Low.
Clay	7. 6	42. 2	Low	Do.
Clay	7. 9	50. 0	Do	Medium.
Clay	6. 7	43. 0	Medium	Low.

[1] As determined by extraction methods published by Arnold and Kurtz (*1*).
[2] As determined by extraction methods published by Bray (*9*).
[3] Based on ovendry weights.

TABLE 5.—*Comparison of high-wall strata and bank characteristics 2 years after stripping, Columbiana County, Ohio*

HIGH WALL

Strata (top to bottom)	Thickness	Acidity	Available phosphorus	Available potash
	Feet	*pH*		
Topsoil	½	6. 3	Medium	Low.
Subsoil	1	5. 2	do	Do.
Outcrop, coal	1	4. 7	Low	Do.
Clay	5	4. 5	do	Do.
Sandstone	13	5. 8	Medium	Do.
Shale	22	6. 1	High	Do.

BANK SURFACE (4 samples)

Texture	Acidity	Amount of stone	Available phosphorus	Available potash
	pH	*Percent*		
Clay	6. 2	61. 0	High	Low.
Clay loam	6. 4	82. 0	do	Do.
Clay	6. 4	57. 0	Medium	Do.
Clay loam		56. 0		

be presented fully here. Detailed descriptions of these variations have already been published (*13, 17, 26, 27, 30, 32, 33, 34, 37, 45*).

An appraisal of these parent materials should therefore be a part of any survey made to determine reclamation procedure. They can quite often be isolated and sampled on bank surfaces. But usually the most convenient place to do this is in the last cut or high wall separating stripped and unstripped areas (fig. 9). In these locations each stratum in the overburden can be identified, sampled, and studied separately. These studies may also reveal ways to modify current and future operations so that highly acid strata can be buried and fertile materials (such as loess and calcareous shale) can be placed on the tops of banks. The following descriptions of strata commonly occurring on land strip mined in the Central States are given chiefly to aid the practitioner in evaluating sites for tree planting.

Limestone

An abundance of limestone on bank surfaces generally means favorable chemical reaction and high productivity. Limestone may occur in the overburden in forms ranging from thick, massive strata to small grains or nodules in other strata. Although it varies in hardness, limestone usually weathers rapidly upon exposure to air on bank surfaces. Unless mixed in the stripping process with hard, slowly weathering shales and sand, the soils formed from limestone strata are almost invariably compact, plastic, cloddy clays.

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TABLE 6.—*Average characteristics of individual strata from eight high walls adjacent to strip-mined land in Illinois (49)*

Strata	Thickness	Texture	Soil separates			Acidity	Available phosphorus [1] per acre	Available potash [1] per acre
			Sand	Silt	Clay			
	Feet		*Percent*	*Percent*	*Percent*	*pH*	*Pounds*	*Pounds*
Topsoil	0–1. 5	silt loam	7. 4	68. 4	24. 4	5. 0–7. 0	22	215
Lower Peorian loess	0–18	silty clay loam	12. 4	59. 5	27. 8	5. 2–7. 7	140	209
Sangamon loess	2–9	silty clay loam	10. 9	60. 7	28. 4	7. 0–7. 9	104	180
Glacial till	5–30	clay loam	25. 3	40. 5	31. 3	4. 4–7. 9	87	188
Yellow shale	4–50	silty clay loam	14. 7	51. 6	33. 7	7. 2–8. 3	109	196
Gray shale	4–50	silty clay	8. 2	48. 6	43. 2	7. 6–8. 1	122	268
Blue shale	4–50	silty clay	2. 1	48. 9	50. 7	7. 3–8. 3	200	304

[1] For a 6-inch thickness.

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FIGURE 9.—High walls formed by strip mining are often good places to study overburden characteristics.

Sandstone

Sandstones are commonly found in strata overlying coal seams. They vary greatly in hardness and weathering characteristics. Some are so hard and massive that they make stripping difficult, whereas others may be so soft that they can be crumbled between the fingers. The hardness and chemical reaction of sandstone depend chiefly on the kind and amount of material cementing the quartz particles together. The principal cementing materials are silica, calcium carbonate, hydroxides of iron and aluminum, calcium sulfate, calcium phosphate, calcium fluoride, and barium sulfate (*35*). There are, then, siliceous, calcareous, and ferruginous sandstones, and their chemical reaction depends mainly on which of these binding materials predominates. Weathering rates are similarly affected; "Calcareous cements dissolve easily, iron cements dissolve less quickly and easily, and sandstones with siliceous cements, especially the quartzites, are very resistant to weathering" (*19*).

The relative amount of sand and sandstone on the surface of banks greatly influences the texture, structure, and consistence of the soils formed. Soils containing a high percentage of sand have low water-holding capacity and high infiltration and drainage rates. Mixed with silts and clays, sand makes resulting soils more porous, less plastic, and less cloddy. Except for the calcareous sandy banks in northern Illinois, the sandy banks in the region are generally acid in reaction, often very highly acid.

Shale

Shales—close-grained, laminated rocks—are much more variable in composition than the limestones and sandstones. They may be sandy, silty, or clayey; thin-bedded or thick-bedded. Acidity may range from highly acid to highly alkaline, even in the same overburden. As in other rocks, the rate of weathering varies according to the hardness and cementing materials of the shales. Some are highly weather resistant and may remain near bank surfaces for centuries. Others are so soft that they disintegrate shortly after stripping.

With a few exceptions most of the highly acid shale occurs directly over the coal seam. The roof coal, if shaly, is very often highly acid. The calcareous shales commonly occur under limestone strata, or, if not associated with limestone, were no doubt formed by geological processes similar to those by which limestone was formed.

Unless definitely sandy in texture, shales usually weather to clayey soils. They differ from the clay soils derived from limestones because they are generally less plastic, contain more slowly weathering rocks, and have better aeration and drainage than the limestone-derived clays. Because of their platy, laminated structure, shaly banks are easily planted by hand methods. The eventual acidity of shale soils, on the other hand, is often difficult to determine, because they usually contain more iron sulfides than the soils derived from limestone.

Clay

Clay strata are common in coal overburdens. They are usually found directly below the topsoil, limestone strata, "rider" coal seams, or in stratigraphic positions where coal seams are expected but absent. Coals seams are almost invariably underlain by a stiff, plastic, impermeable clay, which forms a watertight floor for lakes and ponds in the "final cut."

Clays found directly beneath coal seams, or where coal seams are expected, are usually highly acid and plastic; those beneath limestone strata are often calcareous but variable in plasticity. Clays are very important constituents of bank materials; the productivity of banks depends to a great degree upon the percentage of clay in the surface mixture.

Loess

Perhaps no strip-mined land is more productive than that containing a high percentage of loess on its surface. Composed mainly of silt, with small amounts of sand and clay and no stone, loess soils appear to offer optimum conditions of aeration and moisture and nutrient availability for many plants. Such soils are generally neutral or calcareous in reaction. However, they do erode easily so, to prevent serious gullying, immediate revegetation after mining is necessary (fig. 10).

Thick mantles of loess are common on many strip-mining areas in Illinois, and certain parts of Indiana, Iowa, and Missouri. Where they occur, it is highly desirable reclamation to modify mining methods, if necessary, to place a large amount of loess on the surface of the banks.

Glacial Material

Much of the strip-mined land in the country has been glaciated. The character of glacial till is also quite variable. In texture it is generally a stony sand, sandy loam, or sandy clay. Although reaction varies from highly acid to alkaline, most of the material is in

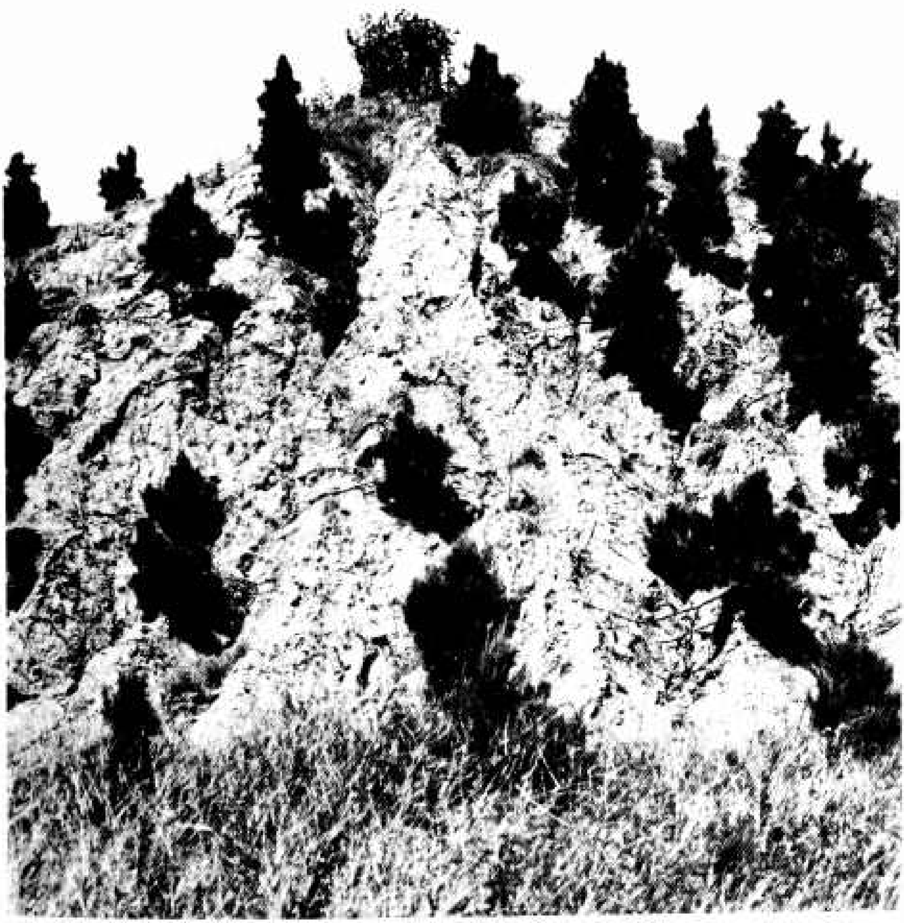

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FIGURE 10.—This bank, composed mainly of loessal material, is very productive but susceptible to severe gullying.

the favorable range of pH. Because of its extreme varied character, a careful appraisal of this material in the high wall is desirable.

The thickness of the soil mantle in the glaciated region varies according to topography and the number of glaciers that have covered a given locality. In the glaciated section of the Ohio mining region, for example, glacial debris is thin or absent on the tops of hills, and relatively thick in the valleys; glacial till is generally thicker in the northern part of the mining region in Indiana, which was covered by glacial material from at least two ice ages (the Wisconsin and Illinoian), than farther south where there is evidence of only the Illinoian glacial epoch.

Alluvium

Alluvium occurs in significant quantities only in the bottoms of relatively narrow valleys. Most of the strip mining for coal in those parts of the region characterized by hill and valley terrain is on hillsides. Where mining does occur in valley bottoms, however, alluvium makes up a good deal of the overburden. It is generally fertile material, ranging in texture from sand through sandy loam to silty loam. Acidity conditions are usually but not always favorable.

Soil

The amount of the original soil in bank materials is usually very small, in fact, almost insignificant. This is especially true in hilly and gently rolling sections, where geologic erosion combined with poor land use in the past has resulted in soil losses and impoverishment. Where soil does still exist, however, and is placed on the tops of banks, it will add to the productivity of the land. Topsoil, especially, contains a wealth of valuable micro-organisms that hasten weathering and make the bank surfaces more fertile. Seeds and plant parts contained in the topsoil may speed soil development. However, in localities where soils have been seriously eroded, growth of trees, and even forage crops, on some banks where the topsoil has been buried deeply, has compared so favorably with growth on adjacent unmined land that the value of topsoil in strip-mine reclamation in these localities has perhaps been overemphasized in some current literature. The addition of soil to surfaces of strip-mined land in England has in general resulted in no more plantation success than when it was not used (*58*).

Methods of Mining

Variations between high wall and bank characteristics are due primarily to the methods of mining employed to remove the coal. The order in which the overburden is placed on the banks has an important effect on bank site quality and should therefore be carefully considered in reclamation plans.

Most strip mining today is done by power shovels and draglines, used singly or in tandem (fig. 11). The character of the material placed on the surface of banks in stripping operations has an important bearing on the future productivity of this land. Consider, for example, the wide difference in survival and growth that would be

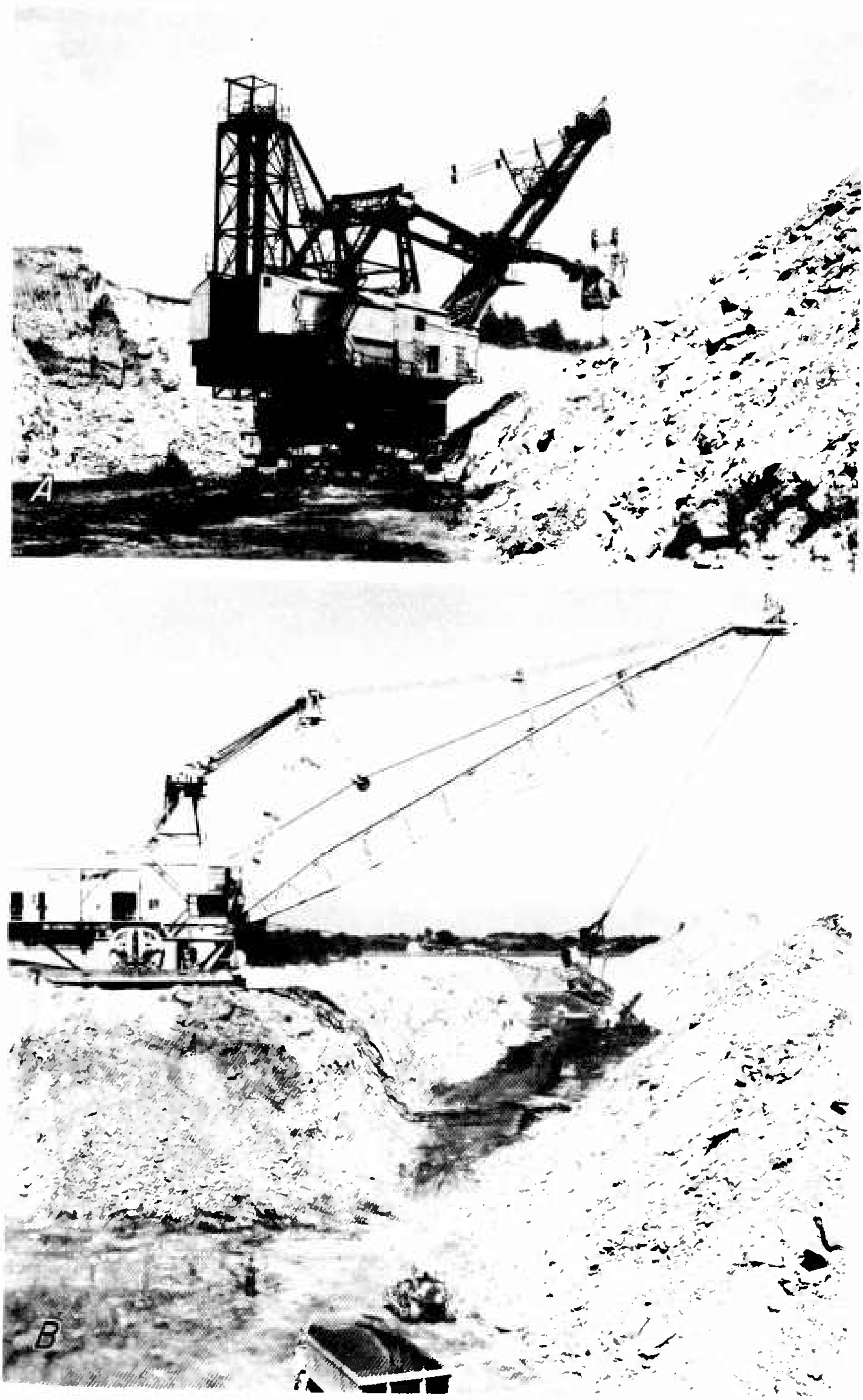

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FIGURE 11.—Most of the strip mining for coal today is done with huge power shovels (*A*) and draglines (*B*) operating singly or in tandem.

expected between a toxic clay and a calcareous shaly loam. One solution to the problem is to so manage the stripping operation that the material which would make the best possible medium for plant growth is placed on top of the banks. Tandem operations—where the dragline is located on the surface of the unmined land and the shovel is located in the "pit" below—offer the greatest opportunities to alter the order of placing different types of materials on the banks. It is often easier, for example, to bury material from a highly acid stratum by tandem mining than by the other common stripping methods.

Modifying mining procedures in this way increases costs, however, and so perhaps should not be advocated except where definite and exceptional improvement in growing conditions is needed and can be attained. If plantable banks would result by modifying stripping procedures on banks that would otherwise be toxic, the change in mining methods should be considered. It is desirable only in those operations where (1) highly acid material would be placed on the surface of banks, (2) the strata containing those highly acid materials can be identified and isolated, and (3) it is feasible to bury all this material in the banks.

Grading

To grade or not to grade strip-mine banks is one of the most pertinent questions in reclamation work. Required in some States by legislation, and often motivated for esthetic reasons, it is usually the most costly part of the job. There is no doubt that grading plays a part in landscape improvement, but, aside from esthetics, the need for grading varies with the intended land use. For example, grading is desirable and usually necessary for the production of farm crops on strip-mined lands, whereas the need for grading on lands to be planted to trees may not be of the same importance. Some of the effects of grading are beneficial, others detrimental. In the discussion following, only the effects of grading strip-mined land on forestation are considered.

Types of Grading

Most of the grading on strip-mined land is done by bulldozers and draglines; on the larger operations carryalls are also used. Grading can be classified as smooth or rough, depending on the surface smoothness desired.

Smooth grading leaves a nearly uniform surface and buries large stones; it is more expensive, and the necessarily more frequent movement of tractors and other heavy machinery over the surface compacts the soil and leaves it more impervious.

Rough grading results in a more uneven surface and leaves boulders on the surface. Less compaction takes place, and weathering and sheet erosion soon ameliorate the rough appearance.

There are also three general types of grading based upon the topography desired:

Complete grading.—The entire stripped area except the final cut is leveled or graded to the degree needed for the operation of farm equipment (fig. 12). This usually leaves a gently rolling topog-

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FIGURE 12.—Mine banks graded to gently rolling topography, for production of forage.

raphy, but it is the most expensive type of grading and results in the most compaction of bank surfaces.

Terrace grading.—Two or more sections of the area are graded to different elevations, often separated by ungraded slopes. The graded sections may be level or gently sloping. On narrow strippings there may be only one graded section, sloping generally from an ungraded outside slope to the high wall (fig. 13).

Strike-off grading.—Only the tops of the ridges are graded to widths usually varying from 10 to 20 feet (fig. 14). The main purposes of "strike-off" grading are to make the area more accessible and to flatten conical peaks of earth and serrated ridges. This is the type of grading practiced on most lands to be planted to trees, unless more complete grading is required by law.

Grading and Soil Moisture and Aeration

Experiments conducted during the past decade indicate that differences in moisture content of graded and ungraded strip-mined land vary with the texture of the bank materials and become more pronounced during periods of drought or excessive precipitation. Preliminary tests on three different banks in Ohio disclosed a significantly higher moisture content in ungraded banks of heavy clay than in similar graded banks after a 10-day period having less than 0.3 inch of rainfall. On banks with lighter, somewhat sandy texture, the differences were not significant. Because of low infiltration rates

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FIGURE 13.—On narrow strippings, the top of the single ridge may be graded to slope inward toward the high wall.

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FIGURE 14.—"Strike-off" grading. Only the tops of ridges are graded to improve accessibility.

on graded banks, most of the precipitation was lost through evaporation and runoff. However, at the end of 10-day periods with more than 0.6 inch of rainfall, the graded parts of the clayey banks were wetter than the ungraded banks. This is because water percolates through graded banks so slowly that clayey banks tend to become "water logged." On the lighter, sandy banks, no significant differences in moisture content between the graded and ungraded parts were found at the end of these periods.

A more comprehensive study[2] conducted in 1948 on three different sites in Kansas and Ohio corroborated the results of the preliminary study in 1946 (fig. 15) (*28*). Two banks, one in Crawford County, Kans., and one in Harrison County, Ohio, had a heavy clay texture. The other area, Columbiana County, Ohio, contained more sand and a much lower percentage of clay. On each of the three sites half of the area had been graded, the other half ungraded. During the period of measurement in Kansas, there were prolonged periods of drought and prolonged periods of much rainfall. In Ohio, the precipitation on both areas was about normal for the entire period. The results of this study indicate that in general most of the critical moisture conditions in the top 6 inches were due to drought; at the 12-inch depth most of the unfavorable moisture condition was caused by saturation.

The differences in moisture content of graded and ungraded banks are attributed largely to differences in their rates of infiltration and percolation. The lower infiltration and percolation rates of graded banks are due largely to puddling, or "crusting-over" of the smoothed surface, and to greater density and less pore space caused by the compaction of banks in the grading operations. Several studies, carried out independently by different investigators, have disclosed an amazing difference in the water infiltration rates between graded and ungraded banks. In one study in Ohio, for example, the infiltration rate on ungraded banks was more than four times greater than on the graded banks, and slightly greater than on an adjacent old field (fig. 16). The differences reported by Merz and Finn (*38*) are even more striking.

Vegetation also influences infiltration and percolation rates on both graded and ungraded banks. On ungraded silty clay banks in Illinois, Grandt (*21*) reported field percolation rates of 9.29 inches per hour on barren areas and 13.57 inches per hour on areas of the same texture but covered with vegetation for several years. For the graded section of the same sites, the rates were only 0.89 inch per hour on the barren part and 1.49 inches per hour on the part covered with grasses and legumes. From laboratory analyses of samples from six graded banks of similar texture but with various den-

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[2] Moisture conditions were determined by electrical resistance methods as devised by Bouyoucos and Mick (*5*). Resistance readings of 60,000 ohms or higher at 70° F. were considered indicative of "dry" conditions and in the range of permanent wilting of most plants. Resistance readings of 400 ohms or less were considered indicative of "wet" or saturated conditions, and well within the range of moisture held in excess of the so-called field capacity of soils. The results shown are based on a total of 10,584 readings taken from 72 randomly chosen sampling stations in each of three test areas.

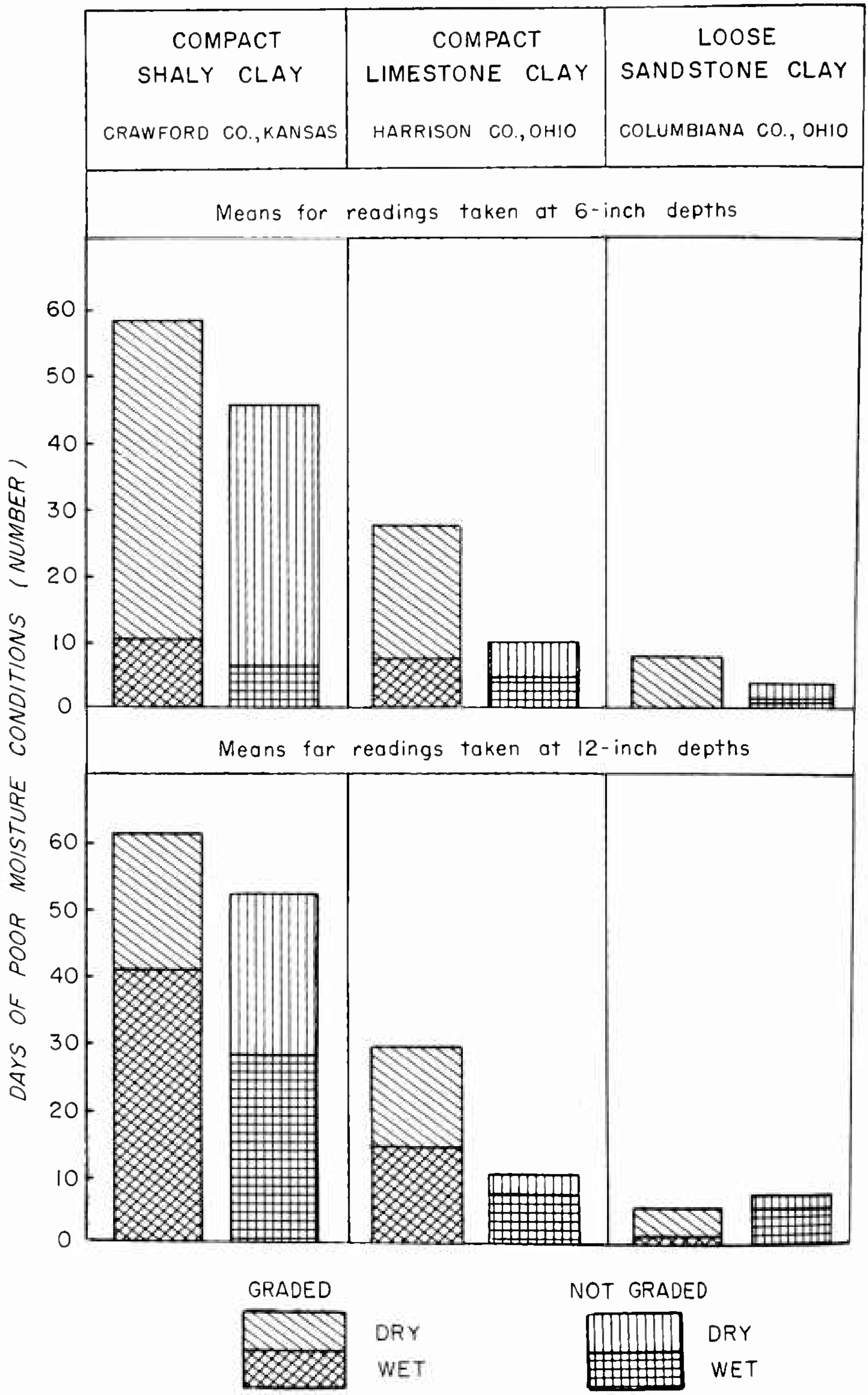


FIGURE 15.—Effects of texture and grading on extreme moisture conditions in bank soils, 1948.

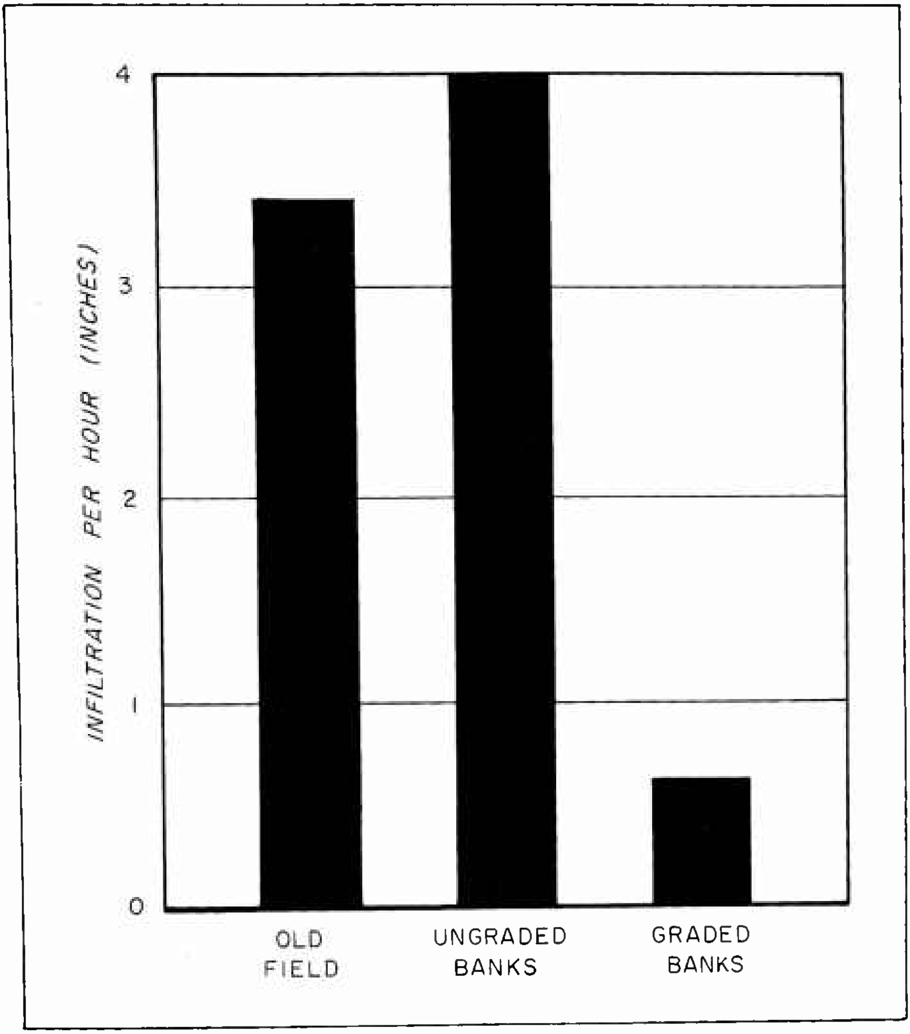


FIGURE 16.—Infiltration on graded and ungraded, strip-mined areas and an adjacent old field, Ohio, 1945. (Tests made with a simulated rainfall device.)

sities of ground cover, Thurn (*49*) found that the percolation rates varied according to the amount of vegetation present from a low of 0.12 to a high of only 1.52 inches of water per hour.

Grading and Microclimate

Because grading alters the topography of a strip-mined area, local climatic conditions are also changed. The typical ungraded area consists of a series of more or less parallel ridges. Only the ridge-tops are exposed to drying winds from two or more directions. Some slopes are shaded most of the day and are cool, while others are exposed to direct sunlight and high temperatures; lower slopes and bottoms are protected areas similar to "coves," which are so favorable for the development of such species as yellow-poplar and black walnut. Graded banks, on the other hand, are relatively uniform in microclimate; exposure to wind and sunlight are generally similar over the entire graded area.

Grading and Survival and Growth of Plantations

For a given site and locality, each species responds differently to the amount of water available for plant growth. Jack pine, for example, may survive longer during periods of drought than white pine. In a similar manner, some species may grow more rapidly in saturated soils than others. Thus there is an upper and lower limit of soil moisture content for the survival and growth of each species. Between these limits is the range of optimum soil moisture conditions. The effects of grading strip-mined land on the survival and growth of plantations are related to the differences already noted in moisture and aeration conditions.

A number of experiments involving a large number of species have been established to study these effects, but conclusive data on the ultimate development of plantations are not yet available. Initial survival and early growth—important factors in stand development—do, however, indicate trends. To date, these trends are the only criteria available for comparing plantation development on graded and ungraded banks. These results, for a number of typical areas and species, are summarized (table 7). Differences in survival

FIGURE 17.—Ten-year-old white pine on graded banks composed of a mixture of sandstone, shale, and clay in Columbiana County, Ohio.

between graded and ungraded parts of the two areas in Ohio, where no prolonged droughts occurred, are not significant; the differences for areas in Kansas and Illinois, where droughts did occur, were significant. Height growth, on the other hand, was significantly better on ungraded than graded parts for nearly all species on all areas tested.

Although some species are more adaptable to graded banks than others, the response will vary from one graded area to another depending upon other site factors. As an example, the average height of white pine 10 years after planting was only 2.5 feet on the graded part of one area but 6.6 feet on the graded part of another (fig. 17).

TABLE 7.—*Comparative survival and total height of trees planted on graded and ungraded strip-mined land at four experimental areas in Ohio, Illinois, and Kansas*

Site	Plantation age	Planting stock—species and age class [1]	Survival		Total height	
			Graded	Not graded	Graded	Not graded
	Years		*Percent*	*Percent*	*Feet*	*Feet*
Limestone, sandstone, shale and clay (Crawford County, Kans.; based on 600 trees of each species).	4	Jack pine (2–0)	8	25	2. 6	2. 6
		Eastern redcedar (1–0).	51	53	2. 2	2. 7
		Black locust (1–0)	72	93	10. 7	13. 9
		Green ash (1–0)	45	59	2. 2	2. 8
		Black cherry (1–0)	20	64	1. 7	2. 1
		Virginia pine (1–0)	20	51	2. 2	3. 4
		Pitch pine (1–0)	18	43	1. 6	1. 8
		Bur oak seed	25	30	. 4	1. 5
		Sycamore (1–0)	16	54	1. 6	2. 7
		Shortleaf pine (1–0).	34	48	. 9	1. 6
Limestone and clay (Harrison County, Ohio; based on 1,350 trees of each species).	10	Black locust (1–0)	85	83	24. 2	25. 4
		White ash (2–0)	85	97	8. 8	11. 4
		Yellow-poplar (1–0).	6	36	2. 3	7. 6
		Eastern white pine (3–0).	60	67	2. 5	4. 2
Sandstone, shale, clay (Columbiana County, Ohio; based on 1,350 trees of each species).	10	Black locust (1–0)	97	93	29. 0	29. 0
		White ash (2–0)	98	95	8. 4	10. 6
		Yellow-poplar (1–0).	72	72	4. 8	6. 7
		Eastern white pine (3–0).	90	60	6. 6	9. 0
Sandstone, limestone, shale, and clay (Saline County, Ill.; based on 200 trees of each species).	10	Green ash (1–0)	83	78	13. 1	10. 8
		Black locust (1–0)	96	84	24. 3	24. 9
		Sweetgum (1–0)	51	66	11. 8	17. 7
		Loblolly pine (1–0).	21	61	10. 7	18. 8
		Eastern redcedar (1–0).	62	68	11. 8	8. 7
		Shortleaf pine (1–0).	24	40	7. 5	10. 5

[1] The first number is the number of years seedling remains in nursery seedbed; the second number is the number of years in the nursery transplant bed.

The first is a highly calcareous, compact, limestone clay, whereas the second is more acid and less compact, and is composed of a mixture of sandstone, hard silty shale, and clay.

Conditions for plant growth are not very uniform on freshly graded banks. On those sections subjected to greater compacting by the grading machinery, growth on the "cuts" is much poorer than on the "fills" (*28*).

Erosion

The susceptibility of newly strip-mined land to erosion depends chiefly on topography and physical soil characteristics. As the length and steepness of slopes increase, the amount of erosion increases. Loessal banks are highly erosive (fig. 10, p. 23). Sandy and silty banks are more erosive than those composed chiefly of clay. Stone on the bank surfaces reduces erosion from raindrop splash. Structure is also important: single-grain or granular materials erode much more easily than cloddy materials. The formation of flat-bottomed, U-shaped valleys, so common on banks consisting mainly of soft shale, is due primarily to the ease with which soil particles and aggregates are washed down the slope.

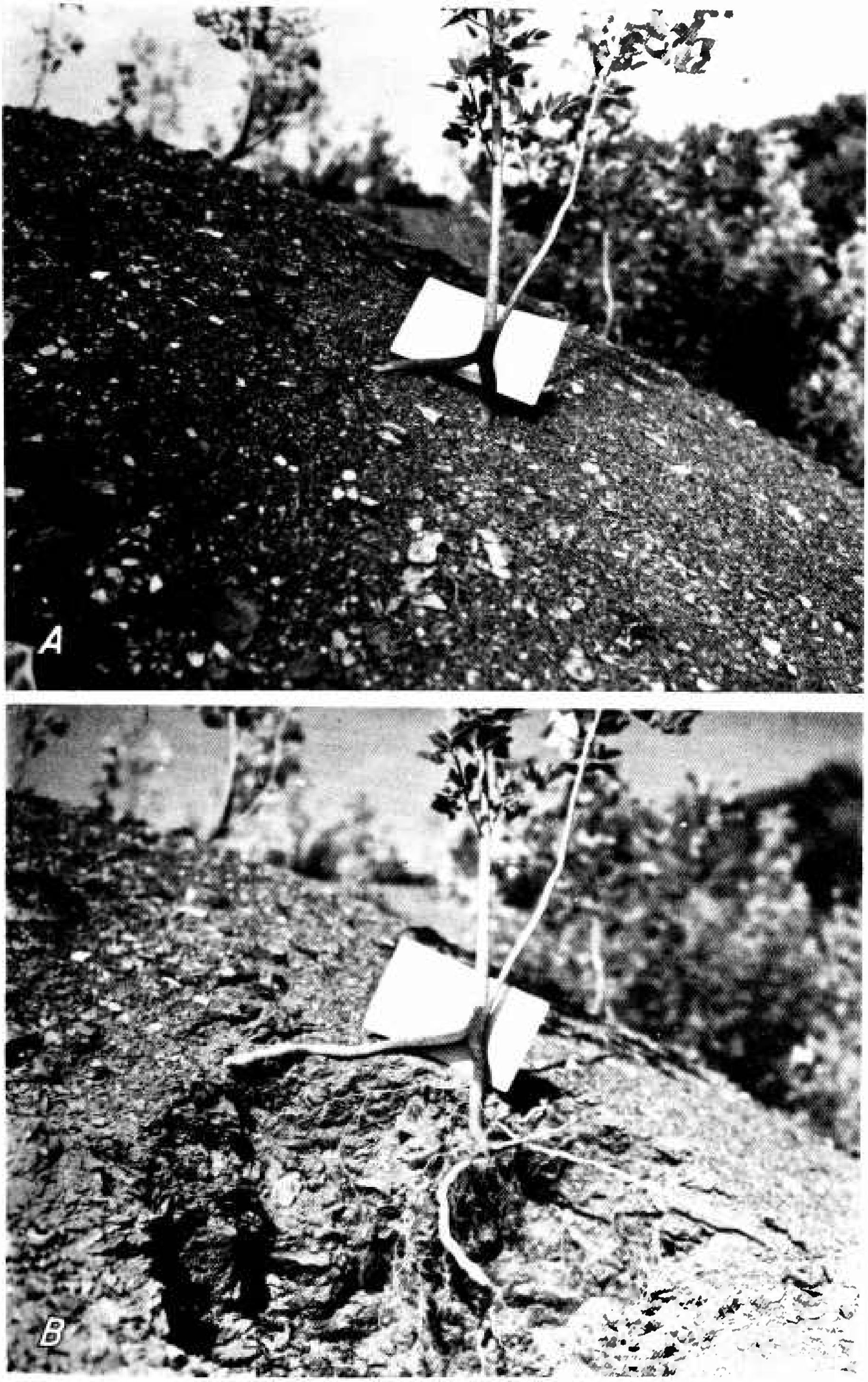
Erosion and Productivity

As erosion proceeds, soil particles and nutrients are washed downward from ridgetops and upper slopes to lower slopes and bottoms. Kohnke (*23*) has shown that alluvial bottoms have a higher pH and contain more nitrogen, available phosphates, and available potash than do adjoining slopes, and that the difference in nutrients decreases with depth. Soil and moisture depths are greater on alluvial bottoms than on adjacent slopes. On highly erosive banks, then, the productivity of the bottoms and lower slopes is often better than on the upper slopes. So erosion accounts, at least partially, for the differences in the growth of trees on the two topographic positions.

Erosion and Forestation Practice

Numerous planting experiments conducted on strip-mined land have shown that mortality on the slopes may be caused by the washing away of soil around the roots of seedlings (fig. 18), whereas losses in the bottoms are often the result of siltation or smothering (fig. 19). More losses from erosion occur on the lower slopes than on the upper. Losses from siltation are generally much higher for conifers than for hardwoods, so planting conifers in bottoms should be avoided. Special studies in Illinois disclosed serious losses from siltation for several species of pine, and eastern redcedar, and for black walnut seed that was buried too deeply for good germination. Of the species tested, black locust, ash, and cottonwood are the least affected by siltation. However, to be safe, no direct seeding of any species should be attempted where much siltation is apt to occur.

On banks flanking silt-covered bottoms, growth of some hardwoods is relatively poor. This is perhaps due to severe exposure of



F–485110, 485109

Figure 18.—White ash on loose, shaly, bank slope 10 years after planting. Note: *A*, Extent of erosion in this period; *B*, the widely distributed root system.

F-485108

FIGURE 19.—This 10-year-old white ash was planted in the flat bottom below the slope (fig. 18). At the time of planting, the fork in the root at the bottom of the picture was at the surface of the bank. Note the many adventitious roots that have formed as a result of heavy siltation.

root systems, a shallower depth of soil for root development, low nutrient content, and a more rapid loss of soil-sized particles by erosion than the gain by weathering processes. On areas susceptible to severe gullying, an increase in the amount of black locust in mixed plantings may be helpful.

THE NET EFFECT

Although the various site factors that affect the survival and growth of trees on strip-mined land have been discussed separately, the specific effect of any one of them usually cannot be isolated or defined because of the combined effects of all the others. In other words, the effect of one factor may supplement that of another, but both may be counteracted by still a third. This makes it difficult to predict just what the net effect of all the site factors on a given spoil bank will be on any one tree species. For example, in eastern Ohio the heights of 5-year-old trees planted on two different mine banks ranged from slightly more than 1 foot to nearly 23 feet depending upon species, topography, and kind of soil (table 8).

Both areas are clayey in texture and were devoid of cover at the time of planting. However, they are different in degree of compactness and acidity: One is a shaly, loose, acid clay, and the other a

TABLE 8.—*Effects of some combinations of site factors on the average heights of species in 5-year-old plantations on strip-mined land in eastern Ohio*

Species planted	Acid, loose, shaly clays		Calcareous, compact clays	
	Ridgetops	Bottoms	Ridgetops	Bottoms
	Feet	*Feet*	*Feet*	*Feet*
White ash	3. 4	7. 8	4. 1	2. 7
Yellow-poplar	2. 7	4. 5	1. 6	1. 9
Black locust	9. 5	13. 7	17. 1	22. 7
Shortleaf pine	2. 7	4. 5	3. 5	3. 9
Pitch pine	3. 4	3. 9	1. 9	1. 6
White pine	1. 6	3. 3	1. 2	1. 3

compact, limestone, calcareous clay. There has been much erosion and siltation on the shaly area; practically none on the other. Trees in the bottoms on the loose shaly clay are much taller than those on the ridgetops (fig. 20). Trees in the bottoms on the compact clay, on the other hand, are only a little taller (sometimes even shorter) than those on the ridgetops.

It is evident then that relief classes alone cannot be used as criteria for the choice of species on lower and upper slopes. On compact clay, growth of white ash is almost as good on the upper slopes and ridgetops as on the bottoms and lower slopes. On the loose shaly clay, on the other hand, growth has been twice as rapid on the bottoms as on the upper slopes. Sorting out the factors accounting for these differences in height growth on the two sites, it appears that: (1) The loose shaly clay has eroded much more rapidly than the compact clay, has thinner surface soil, and has lost more soil nutrients by washing down the slopes to the bottoms. (2) The compact clay has greater water-holding capacity, has a lower percolation rate, and has lost little or no soil and nutrients on the slopes by erosion.

Seldom do two different areas have the same combination of site factors. Very often, however, one or two site characteristics may be dominant, or limiting. High acidity, rapid erosion, or dense cover, for example, could each preclude the choice of a certain species on sites that would otherwise be suitable. Soil texture may also influence the choice of species for planting. In making reclamation plans all important site factors should be considered, and the dominant or limiting factors determined before species are selected.

ESTABLISHING THE FOREST

To get the most profit from strip-mine reclamation, careful planning is necessary. The first question to be answered is what parts of the areas are to be devoted to grazing, recreation, forestry, or other general uses. Then tree planting plans should be coordinated with other developments on the entire area; the intensity of grading, for example, may vary with areas to be used for different purposes.

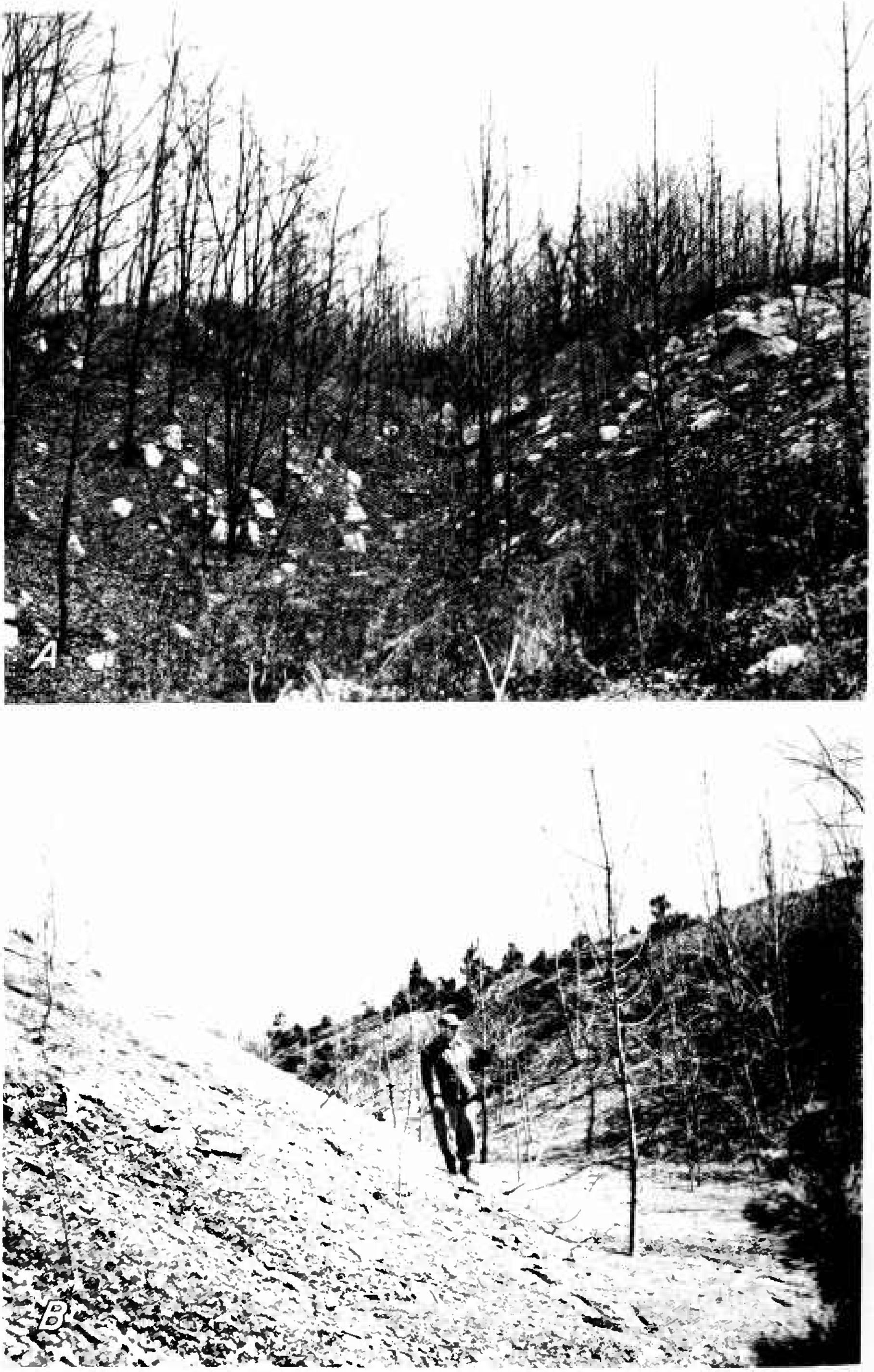


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FIGURE 20.—Ten years after planting: *A*, On compact, calcareous limestone clay, white ash on the ridgetops are almost as tall as those planted in the bottoms; *B*, on loose, acid, shaly clay, trees on the slopes are much shorter than those in the bottoms.

Areas likely to be mined again, for coal in another seam, for clay, agricultural limestone, moulding sand, or other minerals, should not be planted unless such crops as Christmas trees, posts, and mine props can be grown and harvested before restripping is begun. The location of proposed highways, roads, lakes, and other developments should be mapped and excluded from the planting area. Grading should be completed before detailed site evaluations and planting plans are begun. Often adjacent old fields are planted in the same year as the stripped area; for greater efficiency, crew organization, overhead, transportation, and care of stock in both operations should be coordinated. The construction of access roads is highly desirable. Properly located, they reduce cost of planting and provide more efficient plantation management and protection.

Natural Forestation

If adequate stands of forest trees would develop naturally on typical strip-mine banks, there would of course be no forestation problem. But so many elements are against this happening that very few banks have ever been successfully forested in this way. First, unless there is a good source of seed close at hand, very little if any voluntary vegetation will develop. Then, the site conditions found on most mine banks are certainly not conducive to the lodging and germinating of seed. Excessive rockiness of some banks and the smooth, pavementlike surface of others often make it difficult for seed to lodge firmly enough to sprout and take root. And if seed does find a good resting place, erosion is likely to wash it away or cover it. As a result, volunteer vegetation, if it occurs at all, is often more abundant on the bottoms between ridges than on the slopes.

What natural seeding that does occur is done by wind action, so the light-seeded species such as sycamore and cottonwood are the ones most likely to invade mine banks first (fig. 21). On one 2-year-old strip-mine bank that was directly below a forested slope and not more than 120 feet from the seed source, Merz and Plass (*39*) found more than 8,000 seedlings per acre, chiefly sycamore, sugar maple, elm, yellow-poplar, and white oak.

At best, however, naturally seeded forests on strip-mine banks are of doubtful commercial value. One natural stand on stripped land in Indiana appeared very promising before a detailed inventory was conducted (*17*). The age of the trees varied from 1 to 30 years; scattered openings in the stand indicated revegetation was still taking place. Averaging 4,631 trees per acre, this stand composed of hardwoods common to the region, included 4,580 seedlings and saplings less than 4.5 inches in diameter at breast height, 37 poles 5 to 10 inches in diameter, and 14 larger trees. However, only 20 percent of the seedlings were desirable species, and those were poorly formed. The sawtimber amounted to scarcely more than 1,000 board feet per acre and was of low quality, not marketable under current economic conditions.

A natural stand of sycamore on a strip-mined area in Ohio appears to be little more promising (fig. 22). The trees, 16 to 18 years old, average 55 to 65 feet in total height and 5 inches in diameter

F-485128

FIGURE 21.—Cottonwood and sycamore are among the first tree species to invade strip-mined land.

F-485106

FIGURE 22.—Natural stand of sycamore, 16–18 years old on strip-mined area in Ohio. When good, natural stocking is evident within 2 years after stripping, no planting is necessary.

at breast height; the density ranges from 1,500 to 2,500 stems per acre. However, even though many of these trees are straight and of good form, this stand cannot compare favorably in volume with plantations on strip-mined land. The average basal area is only 45 square feet per acre, compared with the 90 to 120 square feet for some plantations of this age.

It is very evident then that artificial forestation is the only sure way to establish fully stocked stands of desirable species on strip-mined land (fig. 23).

F-485105

FIGURE 23.—This land was stripped for coal 35 years ago. Twenty years later the area on the left was planted to shortleaf pine; the bare area on the right has not been planted.

DIRECT SEEDING

On the surface, direct seeding would appear to be the easiest and cheapest way to artificially establish forests on strip-mined land. However, comprehensive tests made during the past decade have shown chances of failure to be so great that direct seeding is risky at best. Although there are some examples of successful direct seeding on strip-mined land, notably black walnut in Kansas (fig. 24) and to a lesser extent bur oak, this method of getting forests started does not appear practical. For the best and most consistent results, planting seedlings is recommended. A few statistics will confirm this.

In 1947 seeds of black walnut, black cherry, and bur oak were sown on 13 different sites in Missouri, Kansas, and Oklahoma. The black cherry seeding was a complete failure. Six years after sowing the average survival for all sites was only 15 percent for black

F-485104

FIGURE 24.—Stands established by direct seeding, such as this 20-year-old black walnut stand in Kansas, are rare.

walnut and 24 percent for bur oak. Another sowing of black walnut seed in Kansas in 1950 resulted in 82 percent survival at the end of 2 years. In still another study, black walnut seed sown on 10 different sites in Illinois in 1947 varied in second-year survival from 6 to 67 percent, with an average of 31 percent. Tests made in Ohio with 11 different species on four sites also gave disappointing results (table 9). Most direct seeding failures are caused mainly by (1) drying out of germinating seedlings, (2) mice and other rodents pilfering the seed (*8*), and (3) erosion and siltation.

TREE PLANTING

The success of any planting on any given site is greatly affected by (1) species planted, (2) quality of planting stock, (3) season of planting, (4) method of planting, and (5) spacing. A wrong decision in any of these matters is perhaps more serious in strip-mine planting than in ordinary field planting. In addition to considering the site conditions just discussed, the prospective planter should consider each of these points carefully before beginning to plant.

Choosing the Species

After evaluating site conditions, perhaps the most critical question confronting the grower is what species to plant. To be considered are these important items: Climate; insects and diseases; and seed sources, hybrids, and varieties.

TABLE 9.—*Germination and first-year survival after direct seeding on strip-mined land in Ohio, by species and site*

Species	Germination				Survival (seed spots with one or more seedlings)			
	Calcareous clay		Acid, shaly clay		Calcareous clay		Acid, shaly clay	
	North slopes	South slopes	North slopes	South slopes	North slopes	South slopes	North slopes	South slopes
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
White ash	0	0	0	0	0	0	0	0
Black locust	17	15	4	3	20	22	1	.7
Jack pine	16	21	8	6	22	40	1	1.5
Pitch pine	22	13	13	4	30	22	2	2.5
Black cherry	.5	0	0	0	0	0	0	0
Shortleaf pine	12	6	4	4	18	10	.3	.4
Loblolly pine	2	3	2	3	8	8	.3	.4
Eastern redcedar	0	0	0	0	0	0	0	0
Sycamore	2	0	0	.3	17	0	0	0
Bur oak	50	48	66	66	50	48	66	58
Black walnut	33	43	11	26	33	43	12	39

Climate

Climate, of course, definitely limits the species that can be grown in any particular area. As a general rule, a species should not be planted on banks out of its natural range unless the climate of the area is very similar to that of the natural range. Some of the important elements that affect climate are latitude, elevation, nearby bodies of water, and topography (*54*). They must be considered when planning to translocate a species.

Many attempts to plant trees out of their natural climate have failed. For example, shortleaf and loblolly pines usually have at least a 50-percent survival when planted within their natural range. However, when these species were planted on mine banks in northern Illinois and Indiana, less than 10 percent survived. Translocating tree species out of their natural range not only exposes them to weather conditions to which they are not adapted, but it also makes them more susceptible to damage or destruction by insects and diseases.

Insects and Diseases

Some tree species are more susceptible to disease and insect damage than others; and this susceptibility varies to some extent in each locality. So one of the first considerations when selecting a species to be planted on an area is its relative chance of escaping serious damage. Have there been any recent infestations or epidemics in the vicinity that would discourage planting of a certain species? Is the species particularly susceptible to a specific insect or disease? These questions should be answered before a final selection is made.

F-258433

FIGURE 25.—Black locust stem seriously damaged by the black locust borer.

No species is entirely immune to such attacks, but some species in some areas sustain more than their share of damage. To date only a few species on strip-mined land have sustained serious losses from diseases or insect attacks.

The locust borer (*Megacyllene robiniae* (Forst.)) is no doubt the most serious pest on strip-mine plantations in the region. The host, black locust, has been planted extensively and is usually seriously damaged by borer attacks within 10 years after establishment. On some sites, however, more of the trees could be utilized than is generally realized, if they were cut as soon as they reach post or mine-prop size. On some banks in Ohio that are not too compact to allow good aeration, nor too loose to result in serious erosion, for example, suitable black locust posts are produced in 8 to 10 years. In 12 to 15 years, however, these trees become so seriously damaged by the borer that they are no longer suitable for posts or mine props (fig. 25).

Young shortleaf pines are often defoliated by sawflies (*Neodiprion* spp.) and at the time of infestation appear to be killed. Usually, however, recovery has been good, with no serious deformity or loss in subsequent growth. Some young red pine plantations in eastern Ohio have been so seriously attacked by the European pine shoot moth (*Rhyacionia buoliana* Schiff.) that this tree species is not recommended in this locality (fig. 26). The larvae of this insect are killed by temperatures below −18° F., particularly in regions where deep snows do not provide protective cover (*15*).

Ponderosa pine was found to be particularly susceptible to a needlecast fungus on strip-mined land in southeastern Kansas (*13*); 18-year-old plantations of this species in this locality—far to the east of its natural range—were completely destroyed by this fungus. The cedar blight, caused by *Phomopsis juniperovora* Hahn, has also caused serious losses in young redcedar plantations.

Sometimes mammals damage planted trees. For example, on some strip-mined land yellow-poplar saplings are seriously damaged by

F-485103

FIGURE 26.—Nearly every tree in this red pine experimental planting on strip-mined land in Ohio has been seriously injured by the European pine shoot moth.

the common woodchuck (*Marmota monax*). Basal scars caused by the gnawing of these rodents expose the inner bark and sapwood to insects and fungi; frequent gnawing of the same tree often results in defect resembling a typical fire scar (fig. 27).

Seed Sources, Hybrids, and Varieties

A knowledge of seed source or the availability of superior varieties and hybrids of desired species is important in planning a forestation project. Only a few seed source or progeny tests have so far been established on strip-mined land. The results of these studies at this early date can serve only as preliminary guides in the current planting programs; they do, however, illustrate the potential

F-485102

FIGURE 27.—Yellow-poplar is often severely damaged by woodchucks. In this tree the damage, continuing for a number of years, has resulted in a defect resembling a fire scar.

benefits that may be gained by applying new findings in this field of research.

In a test of 17 different sources of jack pine from the Lake States planted on stripped land in Indiana, second-year survival and growth of seedlings from two sources—one from northern Wisconsin, the other from central Wisconsin—were far superior to that of others. Great variations in fifth-year survival and growth have been noted in a test of 50 clones of hybrid poplars planted on strip-mined land in Ohio. Average survival varied from 47 to 97 percent, while the range in average total height was 3.8 to 11.1 feet (fig. 28).

What does all this mean? Simply that in the future we may have a better knowledge of seed source and a wider selection of hybrids and varieties suitable for specific site conditions and localities. This will greatly reduce the risk still inherent in any strip-mine planting operation.

F-485101

FIGURE 28.—Heights of various hybrid poplars on strip-mined land in Ohio ranged from approximately 4 to 11 feet 5 years after planting.

Planting Stock Quality

The success or failure of a planting operation depends to a great degree upon the quality of stock used. Because the development of planting stock varies greatly among nurseries—and with different seasons in the same nursery—age alone is not an indicator of stock quality. In the Central States, moreover, plantable stock of many species commonly planted is produced in one growing season.

Stock quality should be judged mainly on the basis of size and balance. Stem diameter, and length and weight of roots in relation to length and weight of shoots are generally considered the best criteria for judging stock quality. Root and top pruning, a common practice in nurseries to adapt seedling size to various methods of planting, also affect stock quality.

Only a few specific studies have been made to determine grading standards in the region. Chapman (*11*) in studying shortleaf pine found that greater stem diameters meant better survival. Similarly, yellow-poplar survival increased progressively as stem diameter increased from 3/20 to 6/20 inch (*31*). Survival declined in seedlings larger than this that had been root pruned to 8-inch lengths (fig. 29).

Top pruning has no significant effect on survival of yellow-poplar or, apparently, other hardwoods. And packing and shipping are often cheaper if hardwood seedlings are top pruned just after lifting in the nursery. Moreover, more top-pruned trees can be carried in planting trays.

In most planting operations roots are pruned to standard lengths, varying with the methods of planting employed. Roots are sometimes pruned to maximum lengths of only 6 inches when planting bars are used; 8 inches when mattocks are used; and sometimes 10 inches when long-bladed grub hoes are used. Because the balance

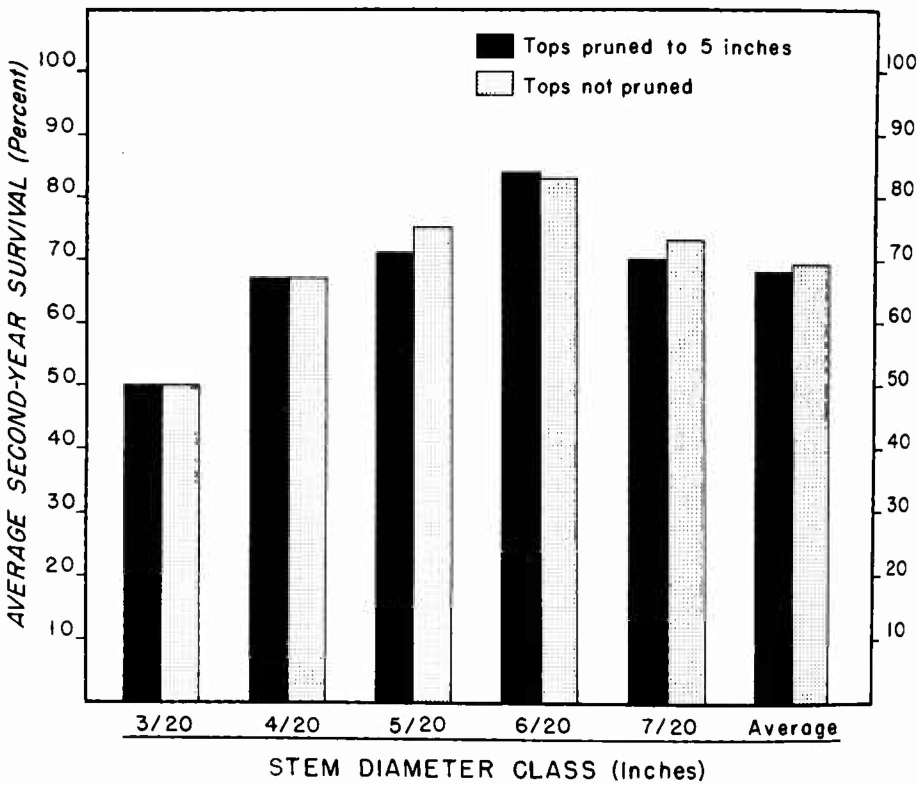

FIGURE 29.—Second year survival of 1–0 yellow-poplar seedlings as related to top-pruning and stem diameter classes. Roots pruned to maximum lengths of 8 inches just before planting.

of physiological processes is involved, the degree of root-pruning may greatly affect initial survival. Root systems of seedlings severely root pruned may not develop sufficiently before the onset of dry weather to supply water when transpiration losses are high.

To be accepted by practitioners, stock grading standards should be simple and easily applied. Grading stock is an expensive and time-consuming job. So if it is found that 80 percent of the stock meets the prescribed standards, grading is unnecessary. The planting stock grades recommended for species commonly planted on strip-mined land in the Central States are based on specific studies and on stock measurements taken from trees planted on more than 30 experimental areas well distributed throughout the region (tables 10 and 11). For conifers the standards are based on stem diameters (at the ground line) and the relation of top lengths to root lengths after pruning. For shortleaf pine, for example, the minimum stem diameter recommended is 3/20ths of an inch; if roots are pruned to 6-inch lengths, the tops should be longer than two-thirds the length of the roots (4 inches) and shorter than 8 inches. For hardwoods, the standards are based only on stem diameters; maximum stem diameters are prescribed only if roots are pruned to lengths of 8 inches or less.

Care of Stock

Daily delivery of stock from the nursery to the planting site is ideal. Because of efficiency, costs, and available transportation, however, this ideal is rarely attained. Planting stock is usually shipped from nurseries to planting sites by railway express or truck. Shipments by freight should never be made. When shipments are made by truck, special precautions should be taken to protect the stock from exposure to sun and drying winds. In an open truck, planting stock should be covered completely by a canvas or plastic tarpaulin.

TABLE 10.—*Planting stock grades for conifers planted on strip-mined land in the Central States*

Species	Minimum stem diameter at ground line	Allowable range in lengths of tops: If roots are pruned to 6 inches	Allowable range in lengths of tops: If roots are not pruned shorter than 8 inches
	Inches	*Inches*	*Inches*
Shortleaf pine	3/20	4–8	6–12
Jack pine	2/20	4–6	6–12
Red pine	3/20	4–6	6–12
Eastern white pine	3/20	4–8	6–12
Pitch pine	3/20	4–8	6–12
Virginia pine	2/20	4–6	6–12
Loblolly pine	2/20	4–6	6–16
Eastern redcedar	3/20	4–6	6–12

TABLE 11.—*Planting stock grades for hardwood planting on strip-mined land in the Central States*

Species	Stem diameter at ground line	
	Minimum	Maximum (if roots are pruned to 8 inches or less)
	Inches	*Inches*
Ash, green and white	2/20	7/20
Cottonwood	3/20	8/20
Maple, silver	3/20	8/20
Oak, bur, northern red, and chestnut	3/20	8/20
Osage-orange	3/20	8/20
Sweetgum	3/20	8/20
Sycamore	2/20	7/20
Walnut, black	4/20	7/20
Yellow-poplar	5/20	7/20

Stock should be planted as soon as possible. If it is necessary to keep stock for 3 or 4 days before planting, moisten the unopened bundles or crates and store in a cool, shaded place. For longer periods, the bundles and crates should be opened, inspected, and moistened, and the trees carefully heeled-in, or repacked and held in cold storage at 34° to 38° F.

If the correct temperature is maintained constantly and if the proper precautions are taken, stock of most species can be safely held in cold storage for at least 3 weeks. The bundles or crates should be opened at weekly intervals and the stock moistened but not soaked. The bundles of stock or crates should be placed separately on shelves so that each can be removed without lifting the others; they should be so arranged that the stock held in storage longest is withdrawn for planting first.

Planting Seasons

The best time of the year for planting strip-mined land in the Central States is in late winter and early spring. Depending on weather conditions, planting may begin anytime from the last week in February to the middle of March and should be completed by May 1. Where cold storage is available, the normal planting season may be extended safely for 2 or 3 additional weeks.

Fall planting usually results in much loss from frost-heaving. In tests made by Chapman (*10*) the average survival and total height of shortleaf pine planted on stripped land in Ohio, 7 years after planting, were 38.6 percent and 8.6 feet for fall-planted stock in contrast to 95.0 percent and 11.0 feet for spring-planted stock. If fall planting is necessary to distribute job loads in large operations, or because of labor shortages in the spring, it should be restricted to banks least susceptible to frost-heaving such as those with moderate to dense ground cover, and to barren areas that are sands or loose, shaly loams.

Planting Methods

Despite modern trends toward mechanization, hand planting will probably continue to be used on strip-mined land for some time. Planting machines have been used to a limited extent on some graded banks that were not too stony or compacted. Such conditions, however, are rare on stripped land in the region.

There are two general hand-planting methods: (1) The slit method, in which roots of trees are placed in slits and packed by pressure from a bar or hoe thrust in the ground 2 to 4 inches from the slit; and (2) the hole method, in which the tree is placed on one side or in the center of a hole, and the roots are packed by hand with loose material (*40*). Slit planting is faster. Planting bars, mattocks, grub hoes, and spades are usually used in hand planting (*50*). The bar is the most common tool used in the slit method, and mattocks or grub hoes are most commonly used in hole methods. The light, short-handled grub hoe, sometimes known as the "Rocky Mountain Planting Hoe," is becoming a popular tool for planting certain types of stripped land. Used with a waterproof canvas bag for carrying stock, it is particularly adaptable to the rough, steep, and stony terrain so characteristic of many banks.

The choice of methods for planting strip-mined land depends mainly upon the physical character of the bank surfaces and the type of equipment available. Tests made in Ohio disclosed little or no significant differences in early survival and growth of yellow-poplar and white pine when planted by slit or hole methods (*32*). Large-scale plantings made by the bar-slit method on stripped land in Indiana have been especially successful. If the bar can be easily thrust into the ground with little or no foot pressure, it is the most efficient handtool to use. When the ground is stony or very compact, the mattock is best.

Planting crews of 8 to 10 planters, with one foreman, are recommended. Foremen should constantly check methods of planting and the condition of the trees in the planting boxes or bags. On dry, windy days, it is especially important to keep trees moist until they are planted. The crew should proceed in echelon (fig. 30); on steep slopes, especially when there is danger of sliding rock, the foreman should see that no planter is working directly below another.

In large-scale planting operations a man or crew specially assigned should be trained to maintain the heeling-in bed or storage facilities, pack trees, and distribute them to the planting crews. This insures proper care of stock from the time it is received to the time it is given to the planter.

Spacing

Spacing of trees in plantations is no doubt one of the most controversial subjects in reforestation. Optimum spacing varies with such features as species, site, locality, and objectives. In general, spacing should be wide enough to postpone the first thinning until merchantable products can be obtained, and close enough to insure good form and development. Conifers as a rule may be planted at

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FIGURE 30.—Part of planting crew, proceeding in echelon on an old strip-mined area. Note use of bars and canvas planting bags.

slightly wider spacings than hardwoods. No more trees should be planted than are necessary to meet the planting objectives. Experiments indicate that a spacing of 7 by 7 feet, now in general use is perhaps the best for most planting on strip-mined land (*7*, *17*). On good sites conifers can probably be planted safely at 8 by 8 feet. A spacing of 6 by 6 may be satisfactory for hardwoods where erosion control is a secondary objective.

Pure or Mixed Planting

Whether to establish mixed or pure plantations depends primarily on the species to be used, and the objectives of management. Silvical characteristics, particularly growth rates and tolerance to shade, and site productivity are factors to be considered. Both types of plantings have their advantages and disadvantages. Pure plantings are easier to establish, manage, and harvest, but they are more susceptible to damage from insects and disease. Certain hardwoods grow faster when mixed with black locust.

In mixed pine plantations, certain species grow so much slower than other species that they may all die before products can be harvested. Hence pure plantings of pine are favored over pine mixtures. If mixtures are desired, they should consist of small groups of rows or blocks of pure plantings. If planted in rows, groups should consist of a minimum of 5 rows of one species, alternated by 5-row blocks of other conifers. With few exceptions (table 15, p.

60), hardwood plantings should consist of mixed plantings, and for some species a mixture with black locust is desirable.

If a "50–50" mixture is used, the two species can be planted separately in alternate rows. If a mixture is to consist of 25 percent black locust and 75 percent "other hardwoods", each row of "other hardwoods" should be flanked by rows with black locust planted in alternate spots.

Black Locust as a "Nurse" Tree

Because black locust has proved to be so beneficial as a "nurse" tree and soil improver in old-field plantations, the practice of interplanting black locust with other species on mine banks warrants special attention. The beneficial effects of black locust in mixed hardwood plantings on old fields have been clearly demonstrated (*12*). So far, the results of planting such mixtures on strip-mined land have been so obscure that acceptance of this practice as standard has at times been challenged. The chief difficulty stems from the fact that black locust often grows much faster on strip-mined land than it does on old fields, so that it soon overtops the associated species (fig. 31). Therefore competition between black locust

F–485131

FIGURE 31.—Four-year-old black locust planted on mine banks (background) and on old field (foreground) in Columbiana County, Ohio. Note difference in height between trees on the two sites, and that crowns of trees on banks have already closed at this early age.

and associated species for light and moisture in mixed stands may become critical at a much earlier age on strip-mined land than on some old fields.

The decision whether to use black locust-hardwood mixtures should depend on the objectives of the reclamation project. Where cover is needed quickly to reduce erosion, or where rapid soil improvement for growth of other trees is desirable, planting black locust, pure or mixed, is recommended. In dense stands of black locust, leaf litter and organic matter accumulate quickly (fig. 32), thereby improving soil aeration, increasing water infiltration, and adding to the organic matter and nitrogen in the soil.

The beneficial effects of black locust on the growth of some associated hardwoods are well illustrated by a planting experiment established on a strip-mined area in southern Illinois. Equal numbers of trees from the same nursery and seed source were planted under a decadent black locust stand and in an adjacent open stand of shortleaf pine. Site conditions were similar at the time of the original planting of locust and pine. Twelve years later the me-

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FIGURE 32.—A good cover of litter has already accumulated under this 6-year-old black locust plantation in Ohio.

dian height of several species in the locust stand was two to three times greater than in the pine stand (table 12). In addition, most trees growing in mixtures with black locust had better form (*16*).

During the past decade, many other experiments testing the value of locust-hardwood plantings have been established. Success of the planting depends upon many elements other than mixtures of hardwoods and black locust, all of which must be carefully evaluated. These include the species planted, quality of planting stock, percentage of black locust used, rate of black locust decadence, site conditions, and timing. By timing is meant whether the other hardwoods are planted before the black locust or at the same time, or are underplanted in the locust stand at a later date.

The most promising species for planting with black locust appear to be red, and chestnut oaks, yellow-poplar, black walnut, sweetgum, green and white ash, and sugar maple; the least promising, cottonwood and sycamore. Redcedar is one of the few conifers that grows well under open black locust stands (fig. 33) until it reaches Christmas-tree size. Redcedar trees growing with and under black locust appear to be a richer green in color during the winter than those planted without locust, a factor worth considering in the production of Christmas trees.

Quality of planting stock, often overlooked, is especially important where competition with fast-growing black locust for soil moisture is great. To assure good survival, sturdy well-balanced seedlings with a minimum of root pruning should be selected (*30*).

What percentage of the trees in a plantation should be black locust? That depends on the other species to be planted, sites, and the expected development of the black locust trees, as well as the desired number of other hardwoods in the final stand, and whether the owner can thin or release the plantations when necessary. Sev-

TABLE 12.—*Effect of pine and black locust on underplanted trees, 12 years after underplanting*

Planting stock species and age	Overstory					
	Open shortleaf pine			Decadent black locust		
	Survival [1]	Median height [2]	Range in height	Survival	Median height	Range in height
	Percent	*Feet*	*Feet*	*Percent*	*Feet*	*Feet*
Yellow-poplar, 1–0	68	9	2–26	48	30	1–41
Black walnut, 1–0	79	13	3–23	73	32	3–36
Black walnut, seed	[3] 71	10	3–20	54	30	4–37
Silver maple, 1–0	63	6	2–13	64	18	6–40
Sweetgum, 1–0	87	13	2–23	[4] 21	11	3–24
Green and white ash, 1–0	84	7	1–12	56	8	1–18
Osage-orange, 1–0	67	7	2–16	46	12	6–21

[1] Basis: 100 trees of each species planted on each site.
[2] Half of the trees taller than median height; half shorter.
[3] Percent of seed spots with one or two living trees.
[4] Most of the mortality caused by rabbits, within 2 years after planting.

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FIGURE 33.—Eastern redcedar grown under open black locust stands in southern Illinois seem to make better Christmas trees than when open grown. These trees, 8 years old when photo was taken, were dead 4 years later; growth was not rapid enough to compete with associated black locust and other hardwoods.

eral studies have been made involving various amounts of black locust in strip-mine plantations. The results, however, have usually been confounded by attacks of the locust borer, which have completely destroyed the locust trees in some plantations and left them untouched in others (fig. 34). Nevertheless, indications are that if too many locusts are planted (more than 50 percent of the stand), some thinning may be necessary in 6 to 8 years provided the borer does not open up the stand first.

In one area in Indiana two stands, one containing 25 percent black locust and the other 75 percent, have been so badly infested with the borer that most of the locust tops are dying and falling down (table 13). Here interplanted yellow-popular has survived and is growing well. In another part of Indiana similar stands that escaped serious borer damage developed such a compact closed canopy of locust that almost all the interplanted yellow-poplar trees died within 11 years. Unless no thinnings or release cuttings are made in such stands, it is doubtful if a sufficient number of trees will survive to form a good stand after the natural breakdown of the black locust.

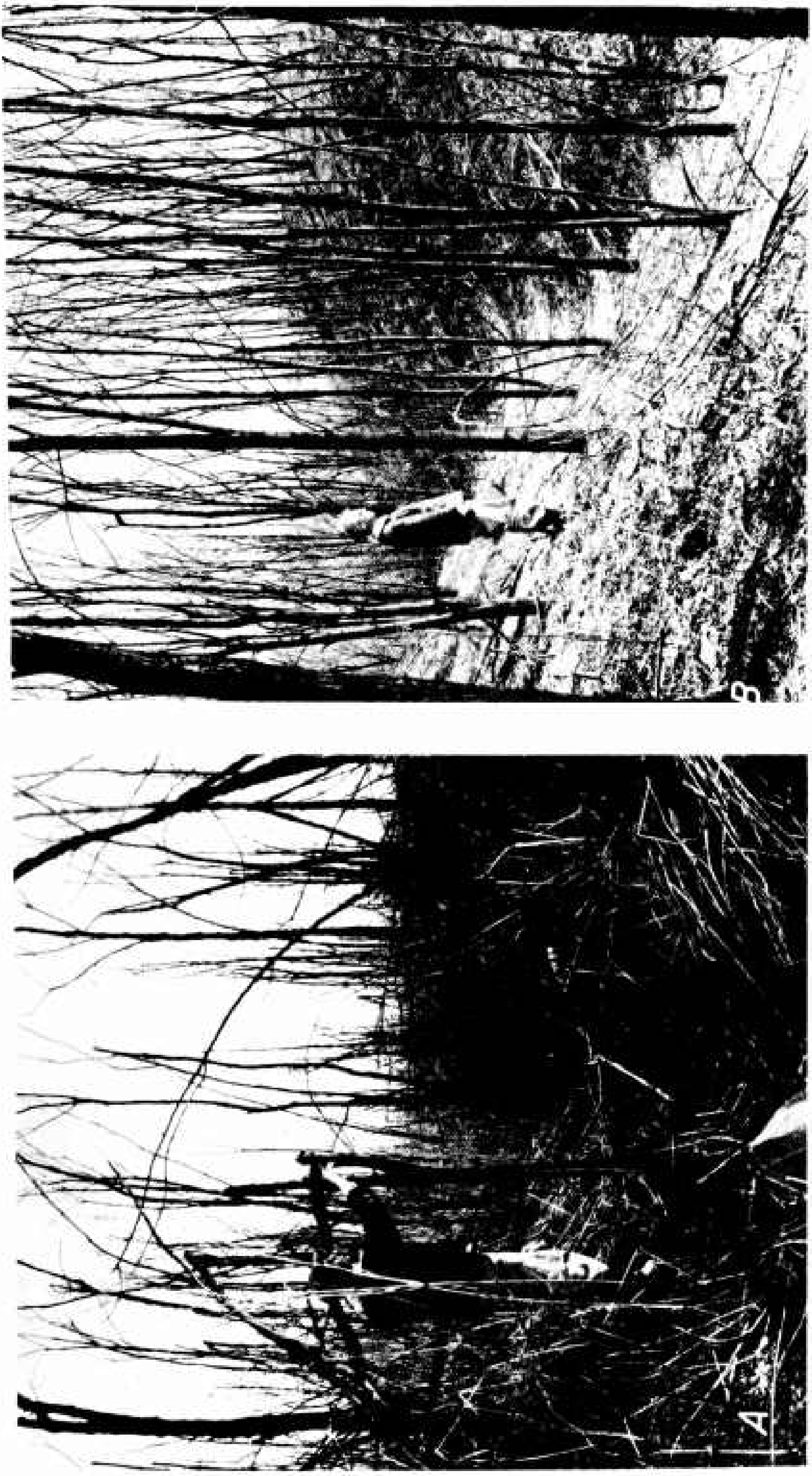

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FIGURE 34.—These two 10-year-old black locust plantations were established from the same planting stock: *A*, Results of locust borer attack; *B*, as yet not attacked by borer. The main difference in site conditions is that soil on the left is compact, while soil on the right is intermediate in compactness.

TABLE 13.—*Effect of rapid deterioration of black locust on survival and growth of other interplanted species, 11-year-old plantations on acid, silty shale in Indiana*

Black locust deterioration and interplanted species	Amount of black locust	Interplanted species		
		Survival	Trees per acre	Height
Fast deterioration of black locust (more than 50 percent dead tops):	*Percent*	*Percent*	*Number*	*Feet*
Yellow-poplar	25	12	81	21
	75	15	33	20
Northern red oak	25	51	344	21
	75	50	112	19
Slow deterioration of black locust (less than 10 percent dead tops):				
Yellow-poplar	25	1	4	10
	75	0	0	----
Northern red oak	25	58	394	17
	75	61	136	7

Basis: 3 plots of 200 trees of each mixture on both sites.

Underplanting in black locust stands has been more successful than simultaneous mixed plantings. This is probably due to improved site conditions and a shorter elapsed time from date of planting to date of natural deterioration of the locust overstory. However, success of either type of planting depends mainly upon these two factors. Tests in stands where the black locust breakdown is almost complete 11 years after planting show promising results for most species (table 14). But on similar plots where the black locust had not yet begun to deteriorate, underplanted yellow-poplar, sweetgum, cottonwood, and sycamore failed completely. If planting is delayed until a dense ground cover has developed under the locust, poor survival may result (*32*).

In mixed simultaneous plantings, survival and growth of the other hardwoods at spacings of 7 by 7 feet have been much better with 25 percent locust than with higher percentages of that species. Such a mixture (usually one row of other hardwoods alternating with rows having 50 percent black locust) permits a wide choice of species, and the costs of later release are greatly reduced, if not eliminated entirely.

Planting costs are increased, perhaps doubled, when black locust is first planted and then later underplanted. In general practice, when high-quality planting stock of the desired species is used, mixed simultaneous plantings containing 25 percent locust should give satisfactory results. Where erosion control or soil improvement is the predominant, immediate objective, pure plantings of black locust appear to be the best practice. Other hardwoods may be planted later when the locust is cut for posts, or when the locust is beginning to deteriorate from borer attacks.

TABLE 14.—*Survival and height of 9-year-old trees planted under decadent 11-year-old stands of 900 black locust trees per acre in Indiana*

Black locust deterioration and species	Survival, trees per acre		Height
	Percent	*Number*	*Feet*
Fast deterioration of black locust (more than 70 percent dead tops, 9 years after underplanting):			
Yellow-poplar	30	270	13
Black walnut:			
Seedlings	70	630	9
Seed	60	540	12
Silver maple	63	567	12
Sweetgum	57	513	10
Green and white ash	80	720	11
Slow deterioration of black locust (15 percent or less dead tops, 7 years after underplanting):			
Black walnut	88	792	7
Chestnut oak	82	738	3
Sweetgum	0	0	----------
Cottonwood	0	0	----------
Sycamore	0	0	----------

PLANTING RECOMMENDATIONS

The species recommended for planting on strip-mined land in the Central States are given in table 15. The major site conditions and the locality of the planting areas, and the natural ranges of the listed species were considered in making these recommendations. All the species recommended have been planted on many areas in the region. The recommendations are based on studies of large-scale and experimental plantings of these and many other species. Several other species, including basswood, baldcypress, tamarack, European and Japanese larches, and Buisman elm (a selection of *Ulmus carpinifolia*), may be suitable for planting on some strip-mined land in the region. Another species, European alder (*Alnus glutinosa* (L.) Gaertn.), appears to be a promising nurse-crop tree. However, until more information is available on survival and growth, only small-scale plantings of these species should be made.

The table is divided into two sections, according to broad soil texture and aggregation classes. The first section includes species recommended for banks that are sandy or loose loams and clays; the second section is for banks that are composed mainly of compact loams and clays.

The following notes may be helpful in using table 15:

Species.—The species marked by an asterisk (*) in the table are preferable for large-scale planting, as well as for stand development and quality of the products. Those not marked with an asterisk are nevertheless satisfactory, and some may be the most desirable for special products. Scotch pine, for example, may be the most desirable for Christmas trees, while Osage-orange may be the best choice for fence posts.

TABLE 15.—*Species recommended for planting on strip-mined land in the Central States*

SANDS OR LOOSE LOAMS AND CLAYS

Species [1]	Acidity range [2] (pH)	Topography	Ground cover	Crown cover [3]	Black locust in mixture (percent)	Strip-mine planting zone [4]
Ash, green*	4 (6–7. 5) 8	Lower slopes and graded banks only.	Light to heavy	Light to moderate.	0–25	All.
Ash, white*	4 (6–7. 5) 8	do	do	do	0–25	1 to 6.
Cottonwood*	5 (6–7. 5) 8	All slopes and graded banks	Light	Light	0	All.
Locust, black	4 (4. 5–7. 5) 8	do	do	do		All.
Maple, silver	4 (6–7. 5) 8	Upper and lower slopes only	Light to heavy	Light to moderate.	0–25	1 to 6.
Maple, sugar	4. 5 (6–7. 5) 8	Lower slopes only	do	do	25–50	1 to 4.
Oak, bur	4 (5–6) 7. 5	Upper and lower slopes only	do	do	0–25	6 and 7.
Oak, northern red*	4 (4. 5–6) 7. 5	do	do	do	0–25	1 to 6.
Oak, chestnut	4 (5–6) 7. 5	do	do	do	0–25	1 to 5.
Osage-orange	4. 5 (6–7. 5) 8	do	Light	Light	0–25	7 and 8.
Sweetgum*	4. 5 (6–7) 7. 5	All slopes and graded banks	do	do	0–25	2 to 4, 8.
Sycamore*	4 (6–7. 5) 8	All slopes and graded banks	do	do	0	All.
Walnut, black	5 (6–7. 5) 8	Lower slopes and graded banks only, but not on sandy banks.	Light to heavy	Light to moderate.	0–25	All.
Yellow-poplar	4. 5 (6–7) 7. 5	do	Light	do	25	1 to 5.
Pine, jack	4 (4. 5–6) 7. 5	All slopes and graded banks	do	Light	0	1, 5, 6.
Pine, loblolly	4 (4. 5–6) 7. 5	do	do	do	0	3, 4, 8.
Pine, red	4 (4. 5–6) 7. 5	do	do	do	0	6.
Pine, Scotch	4 (4. 5–6) 7. 5	do	do	do	0	1 to 6.
Pine, shortleaf	4 (4. 5–6) 7. 5	do	do	do	0	2 to 4, 8.
Pine, Virginia	4 (4. 5–6) 7. 5	do	do	do	0	1 to 5.
Pine, eastern white	4 (4. 5–6) 7. 5	do	Light to heavy	Light to moderate.	0	1 to 6.
Pine, pitch	4 (4. 5–6) 7. 5	do	do	do	0	1 to 4.
Redcedar, eastern	5 (6–7. 5) 8	do	do	do	0–25	All.

COMPACT LOAMS AND CLAYS

Ash, green*	4 (6–7.5) 8	All slopes and graded banks	Light to heavy	Light to moderate.	0–25	All.
Ash, white*	4 (6–7.5) 8	do	do	do	0–25	1 to 6.
Cottonwood*	5 (6–7.5) 8	do	Light	Light	0	All.
Maple, silver	4 (6–7.5) 8	Upper and lower slopes only	Light to heavy	Light to moderate.	0–25	1 to 6.
Maple, sugar	4.5 (6–7.5) 8	All slopes and graded banks	do	do	25–50	1 to 4.
Oak, bur	4 (5–6) 7.5	do	do	do	0–25	6 and 7.
Osage-orange	4.5 (6–7.5) 8	Upper and lower slopes only	Light	Light	0–25	7 and 8.
Sweetgum*	4.5 (6–7) 7.5	do	do	do	0–25	2 to 4, 8.
Sycamore*	4 (6–7.5) 8	All slopes and graded banks	do	do	0	All.
Walnut, black	5 (6–7.5) 8	Upper and lower slopes only	Light to heavy	Light to moderate.	0–25	All.
Yellow-poplar	4.5 (6–7) 7.5	do	Light	do	25	1 to 5.
Pine, eastern white	4 (4.5–6) 7.5	do	Light to heavy	do	0	1 to 6.
Redcedar, eastern	5 (6–7.5) 8	do	do	do	0–25	All.

[1] Species marked with an asterisk (*) are considered the most desirable for large-scale planting. Cottonwood, sycamore, and all conifers should be planted in pure stands or in block mixtures. Other hardwoods, except sugar maple, may be planted in pure stands, but mixtures are preferable.

[2] Figures in parentheses considered most suitable pH range; figures outside of parentheses considered upper and lower plantable limits.

[3] All areas with heavy crown cover considered nonplantable until cover is reduced to light or moderate.

[4] See figure 35 for location of strip-mine planting zones.

The site requirements specified for black locust apply only when this species is planted for wood production. They need not be considered when this species is desired as a nurse crop, for soil improvement, or for erosion control.

Acidity range.—The predominant pH range of the soil on the area to be planted should be determined (procedure described on p. 72). If toxic, the area is nonplantable; if marginal, only such species as black locust, silver maple, Virginia pine, and sycamore should be planted, mainly for soil improvement and erosion control. Numbers in parentheses are the preferred pH ranges for the species; the number before the parenthesis represents the lowest pH plantable for the species; the number after the parenthesis represents the highest pH considered plantable. Maximum and minimum pH ranges were determined largely by field observation of the species on strip-mined land in the region. The preferred ranges are based partly on these field observations and, where these are lacking, from data reported by Spurway (*47*).

Topography.—As discussed in a preceding section (p. 13), topography is considered simply as the following relief classes: (1) Upper slopes, including ridgetops and the upper two-thirds of slopes with total relief of more than 15 feet; (2) lower slopes, including all ungraded banks with total relief of less than 15 feet, or the bottoms and lower third of slopes with total relief greater than 15 feet; and (3) all graded bank surfaces. The slopes created by "terrace" and "strike-off" grading are classified as ungraded banks.

Ground cover.—As classified in a preceding section (p. 15).

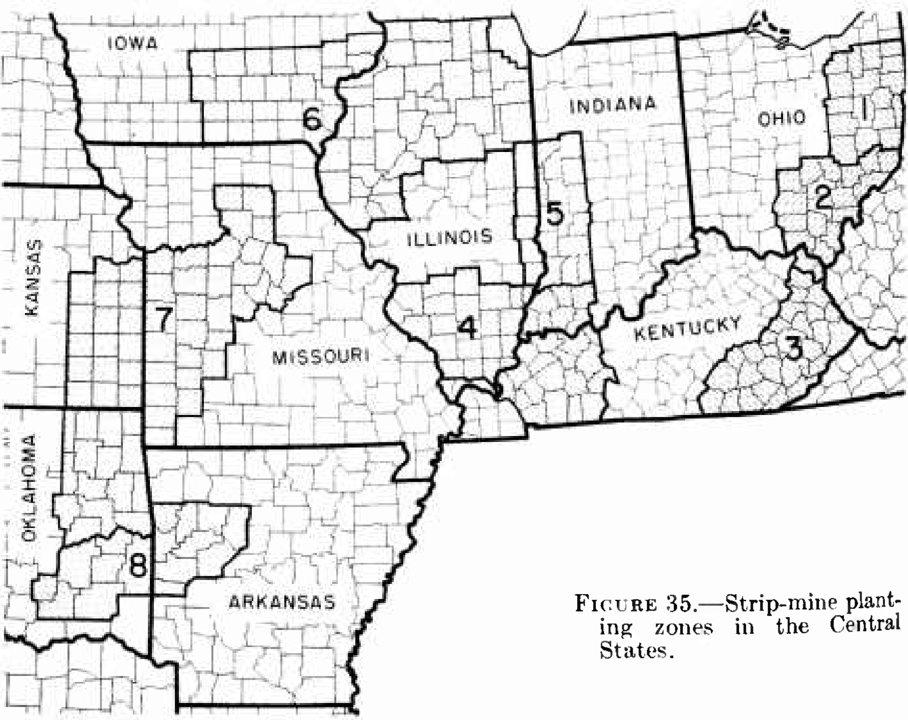

FIGURE 35.—Strip-mine planting zones in the Central States.

Crown cover.—Only areas that have light and moderate densities of crown cover are considered plantable. Areas with heavy crown cover should be thinned at least to moderate density within 2 years after planting. Underplanting dense, unmerchantable black locust stands should be deferred until about 2 years before extensive die-back of tops occurs. This can be determined by close observation of the stands or by comparison with other stands on similar sites.

Black locust mixture.—This column refers to the recommended proportion of black locust to be planted with the species. See discussion on black locust as a "nurse" tree (p. 53).

Strip-mine planting zones.—The species are recommended for planting only in the zones indicated (fig. 35).

GROWTH AND YIELD

Although precise yield data are available only for short-rotation crops, there is some evidence that trees planted on strip-mined land will eventually produce sawtimber as well. The age at which these crops can be harvested depends upon growing conditions on each site and on the desired size of the product. Christmas trees, posts, and mine props can be produced in 5 to 15 years; small poles and pulpwood can be produced in 20 to 30 years. Sawtimber will, of

TABLE 16.—*Growth and yield of 13 different plantations on strip-mined land in Indiana (17)*

Species	Age	Stocking per acre		Merchantable volume [2] per acre	
		Trees	Basal area [1]	Cubic volume	7½-foot posts
	Years	*Number*	*Sq. ft.*	*Cu. ft.*	*Number*
White pine, white spruce	22	525	76	640	640
Jack pine	22	1, 033	97	1, 105	1, 583
Jack, red pine	22	1, 200	97	1, 117	1, 533
Scotch, Austrian pine	21	488	72	968	961
Scotch, Jack pine	21	633	51	498	733
Red, Scotch pine; black walnut	21	833	60	412	450
Red, Scotch, Jack, white pine; black walnut	20	1, 149	112	998	1, 240
Scotch, Austrian, red pine; black locust, black walnut	20	966	84	704	766
Scotch, Austrian, Jack pine	19	884	93	770	900
Jack pine	19	583	44	704	766
Scotch, Austrian, Jack pine; northern white-cedar, white spruce	18	760	108	1, 226	1, 140
Scotch, Austrian pine; black walnut	18	925	93	1, 169	1, 358
Scotch pine	18	600	74	640	583

[1] Does not include intermediate or suppressed trees less than 17 feet tall, or natural reproduction.

[2] Volume of planted trees only; based upon a minimum top diameter of 3 inches, inside bark.

course, take much longer. A few examples will give some indication of what can be expected.

Thinnings made in a 7-year-old black locust plantation on banks in Oklahoma produced more than 330 fence posts per acre; the residual stand and the vigorous sprout growth that followed the first cutting suggested that another salable crop might be harvested after 5 more years (*45*). A 10-year-old black locust plantation in Ohio yielded 600 to 700 posts per acre. Part of a 20-year-old plantation of Scotch and Japanese red pines on mine banks in Indiana was clear cut in 1951 to make way for expanding industrial facilities (fig. 36); the stand cut yielded 3,973 lineal feet of posts and poles from 0.9 acre, which sold on the market for $302. Although immature when cut, this plantation gave a gross return of $17 per acre per year (*17*).

Early growth on strip-mined land of species commonly used to produce long-rotation crops (piling, sawtimber) appears quite good (table 16). For example, at age 20 some species of pine on banks in Indiana were 8 to 14 feet taller than their counterparts in plantations in their native Lake States habitat (*17*). The growth of most red and white pine plantations on strip-mined land in Indiana was about equal to that on old fields of average site quality.

Rogers (*45*) found on mine banks in Missouri 30-year-old black walnut trees about 13 inches in diameter at breast height and 50

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FIGURE 36.—Part of this 23-year-old Scotch and Japanese red pine plantation on strip-mined land in Indiana yielded 3,973 lineal feet of posts and poles on 0.9 acre.

feet high that had good form and were growing faster than the average rate for this species on unmined land in the vicinity. Yellow-poplar trees planted on a stripped area in Indiana were attaining small sawtimber size at 30 years (fig. 37). The evidence to date, therefore, indicates that the rotations required to grow sawtimber on mine banks in the region are no longer than for many adjacent old fields. Growth rates will perhaps vary more among sites on each of these two land types than between the average growth rates of each.

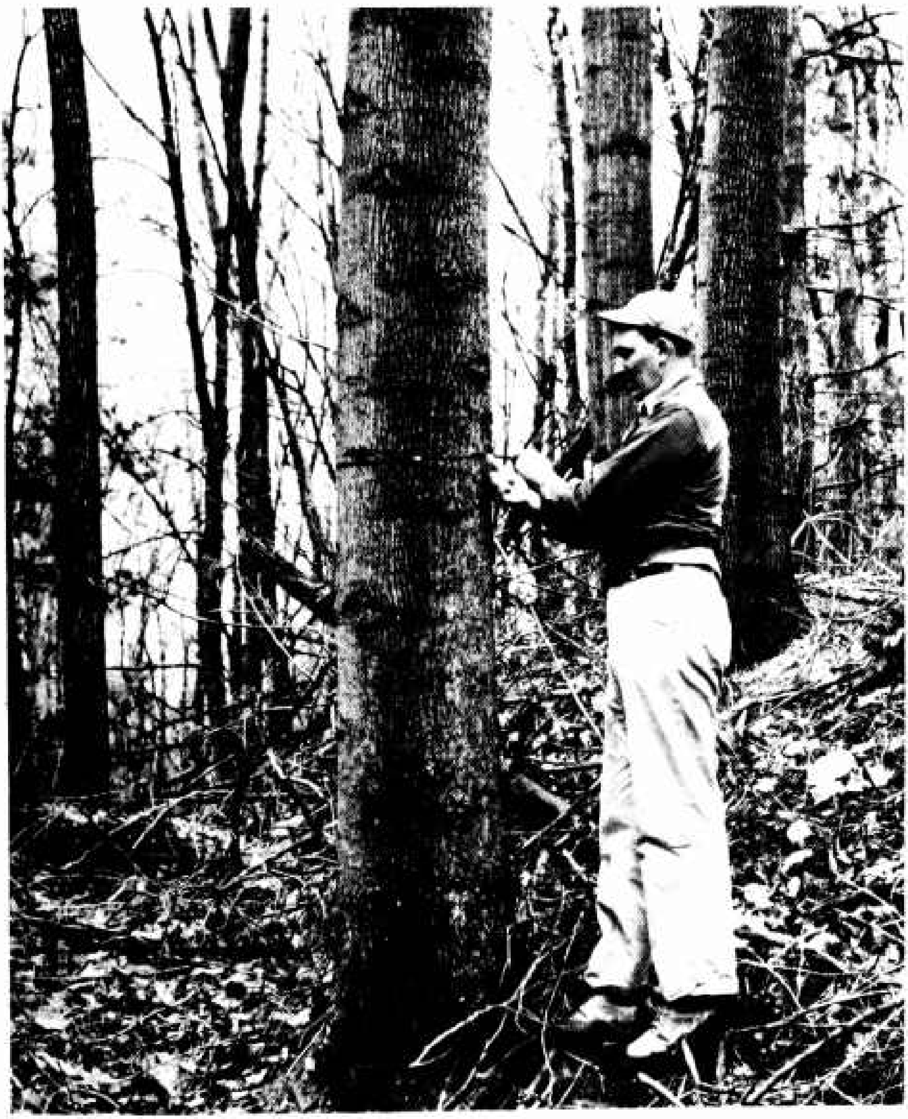

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FIGURE 37.—Yellow-poplar in this 30-year-old mixed hardwood stand on strip-mined land in Indiana is reaching small sawtimber size.

SUMMARY

Strip mining for coal in the Central States region of the United States has created a new type of land surface, with many unique problems related to its rehabilitation and use. One of the best ways to reclaim strip-mined land is by forestation. Most of this land is suitable for the planting of trees and the production of some forest crops, including Christmas trees, posts, mine timbers, pulpwood, poles, and possibly piling and sawtimber. Other benefits of forestation include soil and water conservation and improvements for recreational use.

Forestation usually means planting because neither natural forestation nor direct seeding have proved to be successful ways to establish forest cover on strip-mined land. The soils created by strip mining, generally consisting of material from many rock strata overturned in the mining, are more variable and complex than normal soils derived from a single kind of parent material.

So, to grow trees successfully on strip-mined land, one must carefully evaluate each site and select species that are suitable. Some of the important site factors directly affecting establishment and growth of trees on strip-mined land are the following:

1. *Physical characteristics of bank materials.*—These characteristics include the percentage of stone and the soil texture, structure, and consistency.

2. *Chemical reaction.*—Acidity of bank surfaces, commonly expressed as pH, sometimes limits survival and growth of trees. A pH of less than 4.0 generally indicates that the area is nonplantable.

3. *Topography.*—Exposure or aspect has little effect on early survival and growth; but on many areas growth is better on lower than upper slopes.

4. *Vegetation or cover.*—A dense ground cover reduces survival and growth of many pines and some hardwoods planted on strip-mined land. Overhead cover, sometimes favorable for establishment and early growth, may be a deterrent to later development.

These site conditions in turn are determined and influenced by several things, such as the parent material, methods of mining, grading, and erosion. In addition to the site conditions one must consider susceptibility to insects and diseases, seed source, quality of planting stock, and season of planting.

The use of black locust in mixed plantings, if carefully planned with respect to proportions used and cultural measures needed, will result in better growth of many associated species, such as yellow-poplar, black walnut, red oak, sweetgum, green and white ash, and eastern redcedar. Specific recommendations for planting 23 species are listed.

Growth and yield data for trees growing on strip-mined land are lacking, but indications are that trees planted on such sites will produce salable crops in as short a time as comparable old-field plantations.

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APPENDIX

Common and Scientific Names of Trees Mentioned [1]

Common name	*Scientific name*
Alder, European	*Alnus glutinosa* (L.) Gaertn.
Ash, green	*Fraxinus pennsylvanica* Marsh.
Ash, white	*F. americana* L.
Cherry, black	*Prunus serotina* Ehrh.
Cottonwood, eastern	*Populus deltoides* Bartr.
Locust, black	*Robinia pseudoacacia* L.
Maple, silver	*Acer saccharinum* L.
Maple, sugar	*A. saccharum* Marsh.
Oak, bur	*Quercus macrocarpa* Michx.
Oak, chestnut	*Q. prinus* L.
Oak, northern red	*Q. rubra* L.
Osage-orange	*Maclura pomifera* (Raf.) Schneid.
Pine, Austrian	*Pinus nigra* Arnold.
Pine, eastern white	*P. strobus* L.
Pine, jack	*P. banksiana* Lamb.
Pine, Japanese red [2]	*P. densiflora* Sieb.
Pine, loblolly	*P. taeda* L.
Pine, pitch	*P. rigida* Mill.
Pine, ponderosa	*P. ponderosa* Laws.
Pine, red	*P. resinosa* Ait.
Pine, Scotch	*P. sylvestris* L.
Pine, shortleaf	*P. echinata* Mill.
Pine, Virginia	*P. virginiana* Mill.
Redcedar, eastern	*Juniperus virginiana* L.
Spruce, white	*Picea glauca* (Moench) Voss
Sweetgum	*Liquidambar styraciflua* L.
Sycamore, American	*Platanus occidentalis* L.
Walnut, black	*Juglans nigra* L.
White-cedar, northern	*Thuja occidentalis* L.
Yellow-poplar	*Liriodendron tulipifera* L.

[1] Little, Elbert L., Jr. Check list of native and naturalized trees of the United States (including Alaska). U.S. Dept. Agr. Handb. 41, 472 pp. 1953.
[2] Not listed in check list of official names.

Planting Site Evaluation Record

Planting site No. ________________________________ State ________________
(Acres)

County ______________ Sec. ______________ Tshp. ____________ R. ________
Name and address of owner ____

Possible conflicts with other developments:

Will future stripping cover up part of present surface? ____________________
Any highways, roads, or lakes to be located on area? ____________________

Acidity (Place a dot in the appropriate column for each pH determination.)

Less than 4.0	4.0–4.5	4.6–5.0	5.1–6.0	6.1–6.9	7.0–7.5	7.6+

Estimated percent of surface with pH less than 4.0 ------%; 4 to 6.9 ------%; and 7.0 or higher ------%. Acidity class: ------------------------------
(Toxic, Marginal, Acid, Calcareous, or Mixed)

Physical characteristics:

Estimated percent stone ------ (of which ------% is shale, ------% sandstone, ------% limestone, and ------% glacial).
Texture of soil fraction (underline one): Sandy, loamy, clayey.
Aggregation (underline): Loose, compact.

Stability and Topography: Relief (feet) ------ ------ ------
(Max.) (Min.) (Av.)

Estimated percentage of area in each relief class:
----------------------% (Upper slopes and ridges) ------------------------% (Lower slopes and bottoms) --------% (Graded)

Estimated gradients: -----------% (Slopes) ----------------% (Graded areas)

Is loose material sliding down the slopes? ------ Is there danger of part or entire mass slipping downward? ------
Is erosion slight, moderate, or severe (underline one)? Are valleys between ridges U-shaped or V-shaped (underline one)? Is there evidence of permanent or intermittent ponds in bottoms? ----------

Vegetation:

Ground cover classes (check one): Light ------ Heavy ------
Principal species --
Crown cover classes (check one): Light ------ Moderate ------ Heavy ------
Principal species --

Planting recommendations: Year to plant ------------
Species, spacing, and percent mixture:
On outside slopes --
On upper slopes --
On lower slopes --
On graded areas --
On other areas (specify) ----------------------------------

Planting stock needed:

Species	Number of trees	Stock specification

Access roads: Are more needed to handle the planting job efficiently?

Remarks: --

------------------------------ ------------------------------
(Examiner) (Date)

SULFIDE TESTS[3]

Materials Needed

Geologist's pick (for obtaining unweathered rock samples).
Wide-nosed pliers (for crushing the samples).
12 test tubes (20 x 150 mm.).
¼ pound of granular C.P. zinc (20–30 mesh).
Spiral of wire (a bent paper clip will do).
4-ounce bottle of 6 N. hydrochloric acid (with eye-dropper).
Box of filter paper (Whatman No. 1, 5.5 cm.).
4-ounce bottle of 0.6 N. lead acetate solution (with eye-dropper).

Procedure

Crush 2–3 grams of the material to be tested and place in a test tube. Add about 1 gram of zinc and mix. Insert the spiral of wire part way down the tube to disperse bubbles that otherwise might rise to the top of the tube and spoil the test by contact with the test paper. Add 2–3 ml. (1 eye-dropperful) of hydrochloric acid. Wait about 5 seconds for the fumes to displace the air in the test tube and then cover the mouth of the tube with a small filter paper freshly moistened with 2 or 3 drops of lead acetate solution. Remove the filter paper after 5 seconds. The color and appearance of the deposit produced on the filter paper indicate the amount of potentially active sulfide in the sample, as illustrated in figure 38 and described below.

Color	*Sulfide concentration*
Slight tan coloration	Very low.
Tan	Low.
Brown with tan margin	Moderate.
Dark brown	High.
Black with silvery cast	Very high.

ACIDITY TESTS

Materials and Methods

Relatively simple acidity tests can be made by using a soil testing kit. This test, colorimetric, is applicable to soils ranging in pH from 4.0 to 9.0. Single roll dispensers give sharp color changes for each half pH unit from 0.0 to 14.0. A test for carbonates—indicators of calcareous reactions—can be made by simply placing a few drops of dilute hydrochloric acid on the material to be tested: effervescence indicates presence of carbonates. Toxic reactions can be detected by the use of a 10-percent solution of potassium sulfocyanate (KCNS): if pH is below 4.0, a deep red color appears.

Sampling Procedure

The number of acidity determinations to make depends on the size of the area and the variability encountered. First, tests on a few spots having apparent differences in surface color and texture should be taken to indicate the probable variability of chemical reaction.

[3] Procedure recommended by Deitschman and Neckers (*18*).

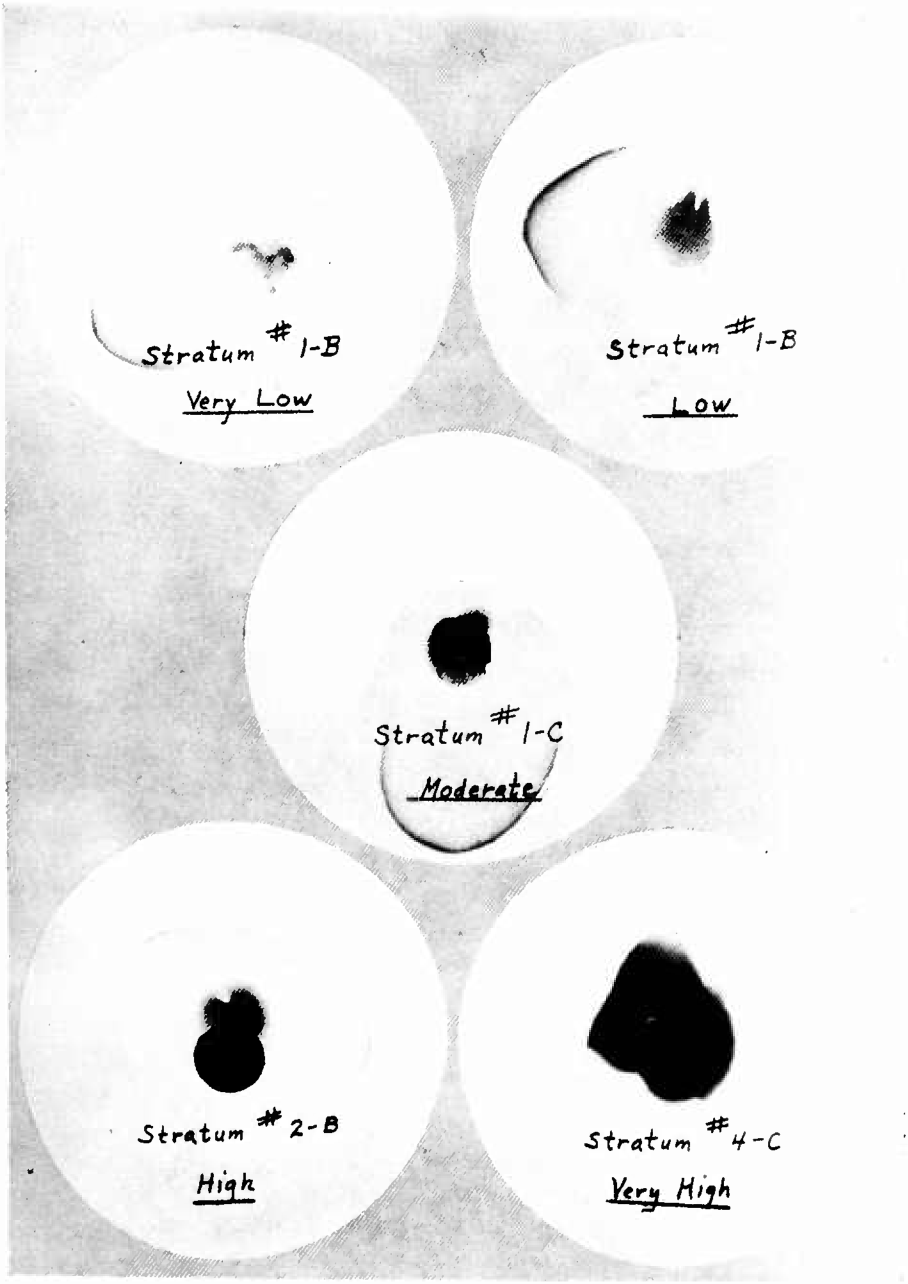

FIGURE 38.—Test filter papers showing the relative coloration produced by very low to very high sulfide concentrations. The margin of the filter paper disk can also be used to record pertinent field notes, as shown.

Very often this will suffice for areas less than 5 acres, and on larger areas where uniform acidity conditions are evident. Where extreme variability is encountered, samples should be taken on strips 400 to 600 feet apart extending across the original contour of the land; on graded areas sample determinations should be made at intervals