RESULTS OF 30-YEAR-OLD PLANTATIONS ON SURFACE MINES IN THE CENTRAL STATES[1]

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Abstract.--Twenty-eight tree species have grown successfully on surface-mined lands in the Central States. Variability in species performance can be related to geographic area, type of rooting medium, and associated species. Many planted stands have been vigorously invaded by volunteer trees, as well as by other plants and animals.

INTRODUCTION AND RESUME

Much of our present knowledge about growing trees on strip mines has been the gift of an earlier generation of tree planters. Thirty years ago, with faith, vision, and energy, they planted millions of trees each year on surface mined lands. They and others have published numerous results of these earlier studies (Ashby, et al. 1978, Boyce and Neebe 1959, Clark 1954, DenUyl 1962, Geyer 1973, Limstrom 1960, Limstrom and Deitschman 1951, Medvick 1973, Rogers 1951, Vogel 1977). It has become a story of success, and even the failures increased our understanding of this skill.

After thirty years, what we have learned about the growing of trees on reclaimed strip mines is considerable. We know that trees have grown successfully on a wide variety of overburden materials. The success of any given species is affected by geographic location, type of rooting medium, and whether it is planted alone or interplanted. Nitrogen-fixing species such as black locust can enhance the growth of associated hardwood species. Both seedlings and seed are suitable for establishing plantings. Where we do not plant at all, it is more difficult for any natural cover to reclaim the mined area.

Planted stands with incomplete cover are rapidly invaded by other trees and by many kinds of plants and animals. This increases the diversity helpful to ecological balances, yet demonstrates that continuing management will be required to maintain the originally-planted trees, if that is desired.

The questions still unanswered after thirty years demonstrate that we hold at present only pieces of information and not a complete fabric of knowledge. We are not yet clear on the relations between soil preparation and the long-term success of plantings. We need to know more about the effects and timing of interplantings of one species with another. And more detailed studies need to be made on criteria for the selection of candidate species, according to soil composition, nutrient availability, climate, and future land use.

We cannot even say what will happen to present plantings over the next thirty years. Invading or interplanted species which apparently accelerated the demise of many pines may similarly later affect other planted species. For maples and oaks, however, this seems unlikely, due to the present relative absence of invading species in those stands.

The effects of grading as practiced 30 years ago are difficult to interpret because of confounding factors such as differing spoil features or grading standards or spoil moisture conditions at time of grading in areas being compared.

We have only limited understanding of solutions to potential problems in planting trees on reclaimed lands protected from erosion by dense herbaceous cover. Although tree plantings were established successfully in pre-existing ground cover over 30 years ago, the density and type of that ground cover was unlike the alfalfa and tall fescue stands usually established for ground cover today. Appropriate species selection and timing in planting the ground cover and trees are possible keys to success. Willis Vogel's paper at this symposium on, "Revegetation of Surface-Mined Lands with Herbaceous and Woody Species Together", addresses this question.

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Now we give an overview of what thirty years' experience has revealed. First we describe our methodology and general results. Next we review special features of individual plantings, examine general characteristics of each species' growth, and briefly discuss the broader considerations of diversification, soil development, and prospects for the future. This includes a perspective on applying these results toward achieving the goals of the Federal Surface Mining Control and Reclamation Act of 1977 (P.L. 95-87).

METHODOLOGY AND GENERAL RESULTS

The plots we examined were located in Indiana, Illinois, Missouri, Kansas, and Oklahoma. We had enough information to locate 867 study plots or sub-plots with a total of 28 species. Trees were planted on a 7-foot by 7-foot spacing, which gave an original planting rate of 889 trees per acre. To sample a plot we typically measured diameter breast height (DBH) of 36 interior trees, or fewer if there were fewer surviving trees. The measurements from the trees in one plot were averaged, and our performance analyses are based on comparisons of these plot averages.

Tabulated, by state, are the number of plots in which all trees of a given species died, the number in which live trees were present and measured, and the percent plots for each species with living trees sorted by mean DBH size classes (Table 1). Species with a relatively low survival rate are identified in the review of individual species. Our data are on all trees, not just the dominant and co-dominant trees.

After 30 years most trees in the strip-mine plantings were in the small-pole size class (4.0 to 7.9-inch DBH). Numerous species were represented in the sapling (0 to 3.9-inch) class and others in the larger pole (8.0 to 11.9-inch) class. Relatively few species were found with plot averages greater than 12 inches. Moderate differences were found in the relative size-class distributions among the several states.

Only 4 species (green ash, black walnut, shortleaf pine, and black locust) were planted and grew successfully in all the states. Of these, green ash was consistently found only in the smaller two size classes, shortleaf pine grew better in Kansas and Oklahoma than elsewhere, black walnut had less good growth in Kansas and Oklahoma, and results with black locust were variable. If present in a state, these species had the largest trees: sweet (red) gum, tulip tree (yellow poplar), loblolly pine, cottonwood, and to some extent sycamore.

Flowering and fruiting were observed for many species and volunteers of the planted species were recorded for many plots. The likelihood of other seed sources for these volunteers was not investigated.

Planting plans

Differences in planting on various plots allowed us to study several interesting problems. Other differences were often not intentional or controlled.

Mixed plantings with black locust.--Some studies in Indiana, Illinois, and Kansas were designed to evaluate the influence of black locust planted with or before other species on their growth. Because some stands were of young (1-3 year) locust interplanted with hardwoods while other stands were of hardwoods planted under older locust already ravaged by the locust borer (*Megacyllene robiniae*), exact comparisons were not possible. In general, locust promoted the growth of tulip tree, black walnut and silver maple, and supressed the growth of pines. In one planting comparing growth under shortleaf pine with growth under black locust, tulip tree, black walnut, silver maple, and osage orange all grew better under the black locust (Fig. 1); only the sweetgum grew better under the pine (Ashby and Kolar 1977). However, all species except silver maple had much greater survival under the pine than under the locust.

Also of note is that the locust stands were vigorously invaded by volunteer species. Unfortunately, in Indiana Japanese honeysuckle (*Lonicera japonica*) often formed dense cover in locust plots and smothered out young trees and herbs.

Row vs. block plantings.--Plantings with several species side by side in rows were used widely in Illinois, and to a lesser extent in Indiana and Kansas. Plantings with just one species in a block were also used, typically ¼ (or ½) acre size in Indiana and 1/10 acre in Missouri, Kansas, and Oklahoma. The chief effect noted was that in Indiana and Illinois pines did considerably better when planted with pines of their own or other species than when interplanted with hardwoods.

Grading.--Studies in Missouri and Kansas, and comparisons in Indiana and Illinois, evaluated the effects of grading on tree growth. The grading was generally less intensive than is carried out under present regulations.

Table 1.--Species Performance by State

Species	No. of Plots		% Live Tree Plots by Mean DBH			
	Trees Died	Live Trees	0 to 3.9"	4.0 to 7.9"	8.0 to 11.9"	Over 12.0"
			INDIANA			
Acer rubrum (Red maple)	--	8	--	100	--	--
A. saccharinum (Silver maple)	--	21	--	86	14	--
A. saccharum (Sugar maple)	--	1	--	100	--	--
Ailanthus altissima (Tree-of-heaven)	--	2	50	50	--	--
Alnus glutinosa (European alder)	--	2	50	50	--	--
Fraxinus pennsylvanica (Green ash)	--	8	38	62	--	--
Juglans nigra (Black walnut)	1	13	8	84	8	--
Liquidambar styraciflua (Sweetgum)	--	19	--	69	26	5
Liriodendron tulipifera (Tulip tree)	2	14	--	36	57	7
Pinus banksiana (Jack pine)	6	2	--	100	--	--
P. echinata (Shortleaf pine)	6	1	--	100	--	--
P. resinosa (Red pine)	6	3	--	100	--	--
P. rigida (Pitch pine)	6	--	--	--	--	--
P. strobus (White pine)	3	3	--	67	33	--
P. taeda (Loblolly pine)	3	--	--	--	--	--
P. virginiana (Virginia pine)	6	--	--	--	--	--
Platanus occidentalis (Sycamore)	--	2	--	50	50	--
Populus deltoides (Cottonwood)	--	4	--	--	75	25
Quercus prinus (Chestnut oak)	--	4	50	50	--	--
Q. rubra & shumardii (Red & shumard oak)	--	10	--	50	50	--
Robinia pseudoacacia (Black locust)	1	3	33	67	--	--
			ILLINOIS			
Acer saccharinum (Silver maple)	2	14	14	64	22	--
Fraxinus pennsylvanica (Green ash)	2	14	29	71	--	--
Juglans nigra (Black walnut)	1	26	12	76	12	--
Juniperus virginiana (Red cedar)	6	9	33	67	--	--
Liquidambar styraciflua (Sweetgum)	1	15	27	46	27	--
Liriodendron tulipifera (Tulip tree)	5	12	--	50	50	--
Maclura pomifera (Osage orange)	--	17	53	47	--	--
Pinus banksiana (Jack pine)	2	12	42	58	--	--
P. echinata (Shortleaf pine)	7	6	--	100	--	--
P. resinosa (Red pine)	7	8	12	88	--	--
P. rigida (Pitch pine)	7	5	20	40	40	--
P. strobus (White pine)	6	7	29	57	14	--
P. sylvestris (Scots pine)	--	2	50	50	--	--
P. taeda (Loblolly pine)	6	6	17	33	33	17
P. virginiana (Virginia pine)	5	7	14	57	29	--
Populus deltoides (Cottonwood)	6	10	--	10	60	30
Quercus alba (White oak)	--	1	--	100	--	--
Q. rubra & shumardii (Red & shumard oak)	--	2	--	--	100	--
Robinia pseudoacacia (Black locust)	--	14	--	93	7	--

Table 1.--Species Performance by State (continued)

Species	No. of Plots: Trees Died	No. of Plots: Live Trees	% Live Tree Plots by Mean DBH: 0 to 3.9"	4.0 to 7.9"	8.0 to 11.9"	Over 12.0"
			MISSOURI			
Fraxinus pennsylvanica (Green ash)	--	13	69	31	--	--
Juglans nigra (Black walnut)	--	15	13	67	20	--
Juniperus virginiana (Red cedar)	1	11	--	91	9	--
Pinus banksiana (Jack pine)	7	2	--	100	--	--
P. echinata (Shortleaf pine)	--	10	--	100	--	--
P. ponderosa (Ponderosa pine)	6	--	--	--	--	--
P. rigida (Pitch pine)	6	2	--	50	50	--
P. taeda (Loblolly pine)	2	8	--	62	38	--
P. virginiana (Virginia pine)	1	8	--	100	--	--
Plantanus occidentalis (Sycamore)	--	11	18	46	27	9
Prunus serotina (Black cherry)	--	13	23	62	15	--
Prunus serotina seed	3	--	--	--	--	--
Quercus macrocarpa (Bur oak)	--	32	44	47	9	--
Robinia pseudoacacia (Black locust)	--	18	--	100	--	--
			KANSAS			
Fraxinus pennsylvanica (Green ash)	3	17	82	18	--	--
Juglans nigra (Black walnut)	2	31	84	16	--	--
Juniperus virginiana (Red cedar)	5	17	12	88	--	--
Pinus banksiana (Jack pine)	3	11	--	100	--	--
P. echinata (Shortleaf pine)	--	14	--	86	14	--
P. ponderosa (Ponderosa pine)	10	3	--	--	100	--
P. rigida (Pitch pine)	5	9	--	89	11	--
P. taeda (Loblolly pine)	1	13	--	24	38	38
P. virginiana (Virginia pine)	1	13	--	100	--	--
Platanus occidentalis (Sycamore)	2	18	5	78	17	--
Prunus serotina (Black cherry)	1	13	46	54	--	--
Quercus macrocarpa (Bur oak)	1	28	54	46	--	--
Robinia pseudoacacia (Black locust)	--	25	--	96	4	--
			OKLAHOMA			
Fraxinus pennsylvanica (Green ash)	--	3	--	100	--	--
Juglans nigra (Black walnut)	--	3	33	67	--	--
Juniperus virginiana (Red cedar)	--	3	--	100	--	--
Liquidambar styraciflua (Sweetgum)	1	2	--	--	--	100
Pinus banksiana (Jack pine)	3	--	--	--	--	--
P. echinata (Shortleaf pine)	--	3	--	33	67	--
P. taeda (Loblolly pine)	--	3	--	--	33	67
P. virginiana (Virginia pine)	--	3	--	33	67	--
Platanus occidentalis (Sycamore)	--	3	--	33	67	--
Prunus serotina (Black cherry)	--	3	--	100	--	--
Quercus macrocarpa (Bur oak)	--	9	33	67	--	--
Robinia pseudoacacia (Black locust)	--	3	--	67	33	--

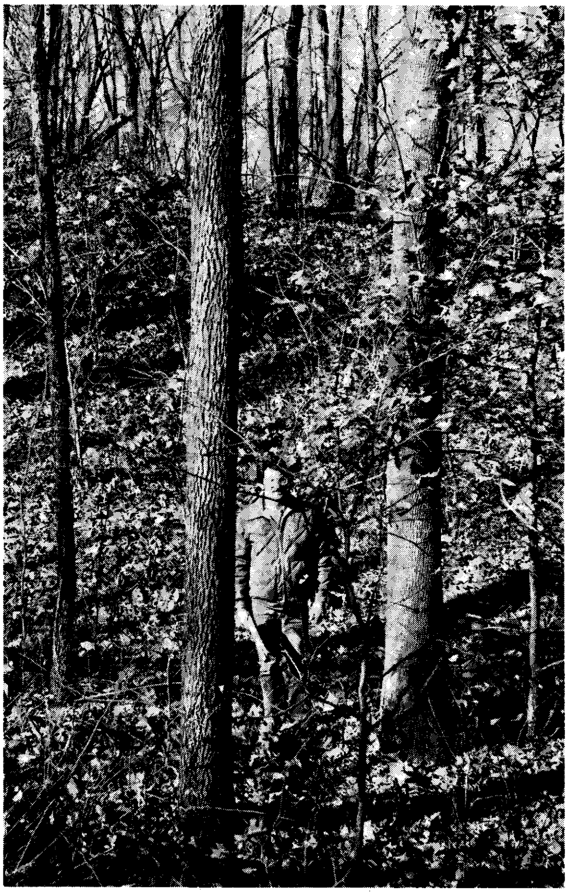

Figure 1.--Decadent black locust stands were characterized by a friable, humus-stained soil enriched in nitrogen and protected from erosion by litter. Black walnut (on the left) and tulip tree (on the right) made superior growth with good form in this southern Illinois stand, which was also rapidly invaded by a diversity of forest species.

In Missouri, growth on graded plots was equal or better than on the ungraded, but the ungraded plots had 68 percent rock compared to only 48% on the graded spoils.[3] Spoil moisture and physical conditions affecting compaction were reportedly ideal at the time of grading. The chemical composition of the spoils seemed to be uniform. These two sets of plots in Bates County had the best growth of any of the Missouri plantings.

[3]Rogers, N.F. 1947. Establishment report for spoil banks planting experiment no. 1. Pittsburg Branch Station of the Central States Forest Experiment Station. Tests of species adptation and growth on strip-mined lands in Oklahoma, Kansas and Missouri. 135 p. and maps.

In Kansas, grading scarcely affected ash, red cedar, or black locust plot averages. Grading reduced the DBH of black walnut and bur oak, while it increased the size of loblolly and shortleaf pine. Soil tests detected little difference between the two spoil areas.

In an Illinois study, most species grew better on a plot graded by dragline pullback than on an ungraded plot. These results may, however, be questioned because substantial differences in rock content and pH (graded plot pH 6.1, ungraded plot pH 3.4) undoubtedly influenced the tree growth.

The most dramatic effects of grading were on apparently uniform Indiana site graded by bulldozer about 1940 and planted to black walnut. In 1977 the walnut averaged 7.4 inches DBH on the ungraded banks and 4.2 inches on the adjacent graded area. While the trees on the graded area had grown well for the first 18 years (Deitschman and Lane 1952), by 1977 they were conspicuously stag-headed with poor canopies and yellow-green leaves. Trees on the ungraded area showed good form and color. Small differences were found in soil pH, phosphorus, and potassium analyses.

Selective placement of overburden.--At one northern Illinois mine calcareous deep sands overlay a dense clay in the overburden. Where a shovel and dragline operation worked in tandem the sand was replaced as the surface rooting medium. On these sites, black locust and black walnut survived better and grew considerably larger than on sites where the dense, less productive clay was left as the rooting medium by a shovel or dragline working by itself. The dramatic differences in tree performance between these two sites indicates the potential benefits of selectively placing or mixing the different layers of overburden.

Use of seed.--Black walnut and bur oak, both with large seed, grew about equally well planted as seedlings or seed. Black cherry did not grow well from seed.

Review of species

Maples.--In pure stands, red and to a lesser extent other maples produced dense canopies with little ground cover beneath them. Silver maple had poor form for a timber tree. Of the silver maples, 53% had multiple stems, regardless of whether they were in pure or mixed stands, while multiple stems were found on only 39% of the red maples and on only 8% of the one stand of sugar maple.

Green ash.--In mixed plantings in Illinois, green ash had the highest survival rate of any species after 30 years.

Black walnut.--Black walnut seemed to be very site sensitive. Its occurrence in three size classes could be related to soil pH, drainage, and other factors. In Indiana and Illinois, where it was often associated with black locust, the tree form of the larger black walnuts was good. The understory or ground layer in walnut stands was visually different from other planting areas. Honeysuckle did not invade beneath walnut in Indiana; instead white snakeroot (Eupatorium rugosum) was a common ground cover there.

Sweetgum.--This species had both good survival and growth after 30 years in the southern part of the Central States. It grew very well at low pH. Some regeneration, probably by both root sprouts and seedlings, was found.

Tulip tree.--Tulip seemed similar to black walnut in site sensitivity. It grew well at lower pH values. Climatically it was limited to the southern parts of Indiana and Illinois, and was not tried in the other states.

Pines.--All pines had better performance overall in pure than in mixed plantings, and in southern compared to northern areas where such comparisons were possible. Loblolly pine outgrew other pines in southern areas, but did not survive on northern plots. Virginia pine, which had poor form, consistently had moderately good survival and growth, except in Indiana where it was planted only under young black locust. Earlier survival and growth of the pines in mixed plantings were commonly good, based on published results and on standing or fallen dead trees observed in the 30 year survey.

Sycamore and cottonwood.--Although these species had some of the largest trees, generally growth was not particularly good compared to what is possible for these species. Mortality of planted trees was high, and volunteer trees of the same species often equalled or exceeded planted trees in size. Tree form of these species was often poor.

Oaks.--The ecological potential of oaks was largely ignored in the early stripmine plantings. Bur oak, planted in the western part of the area, had good stands (Fig. 2). These stands consistently included saplings and small poles. Red oak stands, composed of Q. rubra and the often larger Q. shumardii, were highly successful in southern Illinois and in Indiana, with little understory or ground layer. Chestnut oak in Indiana performed similarly to the bur oak further west.

Black locust.--This leguminous tree made very rapid early growth before succumbing to the locust borer. It built up soil nitrogen levels of over 100 pounds per acre compared to a pine stand (Ashby and Baker 1968, Finn 1953), and contributed a readily-decomposed litter. Soils under locust were relatively loose with a darkened surface layer. Locust grew well over a wide pH range.

Although locust early lost favor for planting, the excessive competition attributed to locust in young stands of interplanted species is scarcely justified by 30-year results of locust with several hardwoods. Locusts may have been harmful to pines, but after 30 years pines exibited poor performance in the absence of locust as well.

Other than limited cutting for fence posts, these locust stands lacked the management needed if high productivity under short-rotation forestry were desired.

BROADER CONSIDERATIONS

Enhancement of diversity

Invasion of trees and herbaceous plants into the tree plantings was considerable.[4] After 30 years, the number of naturally established trees often exceeded the number of planted trees. Volunteer tree sizes were smaller, presumably because the volunteers were younger. Natural invasion was far greater in tree plots than on adjacent unplanted areas. Because of the enhanced diversity, many stripmine plots superficially resembled areas of natural forest regrowth.

However, dense stands of pines, maples, and to a lesser extent, oaks and black walnut, discouraged invasion. Allelopathic chemicals or heavy leaf litter may have reduced invasion on some plots.

Cottonwoods and sycamores, while commonly found in and around the plot areas prior to plantings, did not invade established plantings.

The major invaders under tree cover in all areas were elms (Ulmus spp.), hackberry (Celtis occidentalis) and box elder (Acer

[4]Ashby, W.C., N.F. Rogers, and C.A. Kolar. 1980. Forest tree invasion on stripmines. The Third Central Hardwood Conference. University of Missouri, Columbia. In press.

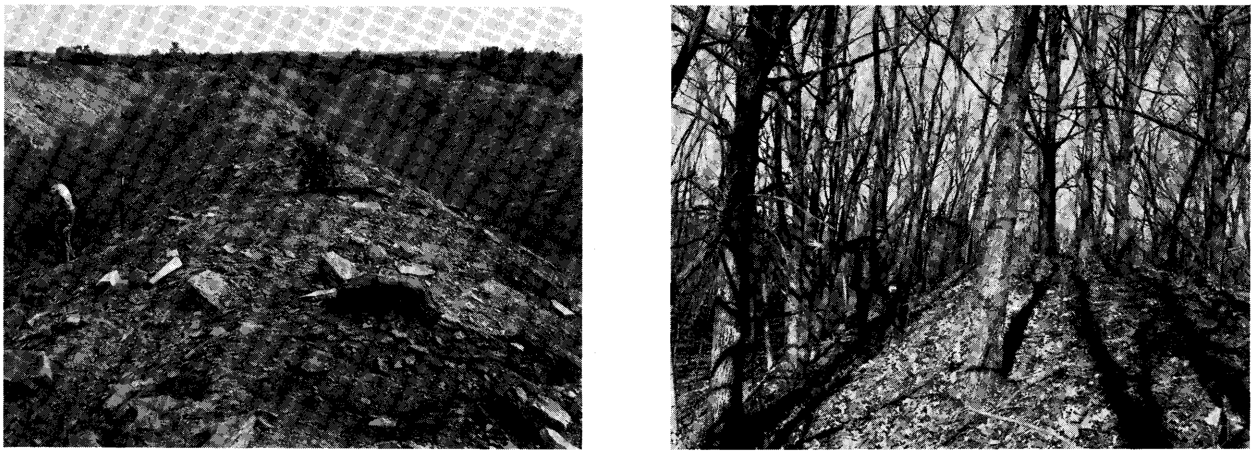

Figure 2.--These well settled slopes in Kansas were seeded with bur oak seed in 1947. Thirty years later the bur oak stand of 275 trees per acre, about 4" dbh and 25 feet tall, was increased by invading black locust, elm and mulberry. The soil was mellow under a leaf and twig litter of more than one inch. Many of the black locust were larger than the bur oak. The tree cover has transformed the once barren landscape. USDA Forest Service photos.

negundo). Other invaders important more locally were black cherry, ashes (Fraxinus spp.), pin oak (Quercus palustris), shingle oak (Q. imbricaria), and sassafras (Sassafras albidum).

Diversity of invading trees was greatest in Indiana with 48 species, and diminished to the west, likely partly as a function of the availability of naturally occuring species. Oklahoma had only 17 species. Many plots not planted in black locust were invaded by black locust in nearby plots. The black locust plots themselves were preferentially invaded by hackberry in Indiana or red mulberry in Missouri and Kansas.

Shrub invaders were chiefly dogwoods (Cornus spp.). Grape (Vitis spp.) had a lesser distribution while other species such as sumac (Rhus spp.) were evident locally.

Many plots had a dense herbaceous layer. Species composition related to type and density of tree canopy and varied from old-field components such as lespedezas (Lespedeza spp.), to pokeweed (Phytolacca americana), to mesic forest species such as white snakeroot. White snakeroot was particularly important in older stands with black locust.

Animal life readily invaded the plot areas. Early invaders such as rabbits damaged the original plantings, particularly sweetgum in Kansas. Locust borer caused severe damage after 10 to 15 years, apparently especially in Indiana and Illinois. Abundant later wildlife includes game and song birds, groundhogs, deer, racoons, and beavers.

Development of minesoils

Our forested plots developed well-recognized O1 litter, O2 fermentation, and A1 humus-stained surface layers. B2 horizons were sometimes suggested by an increase in reddish color or in clay content several inches down in the profile.

Ten soil samples were taken and analyzed in each plot in Indiana and Illinois. Most soils were judged to be loams, based on the feel method and some Bouyoucos analyses for texture. The soils were often neutral-to-alkaline, and rarely more acid than pH 5. Correspondence of tree growth and pH, which could be found for individual species such as poor black walnut growth on acidic soils, was not characteristic for tree growth overall.

Available phosphorus by either the Bray-1 acid-fluoride or the Olsen sodium bicarbonate methods was commonly less than 10 ppm, as is typical of midwestern forest soils. Available potassium was in the general range of 100 to 200 ppm, with occasional appreciably lower or higher values. No deficiency symptoms for either phosphorus or potassium were noted. Chlorotic leaves, possibly from iron deficiency, were noted for sweetgum on a calcareous silty-clay loam soil in southern Illinois.

Prospects for the future

The extensive acreages of pre-law mined land planted to trees will continue to provide the amenities of forest cover for years to come. Stands of red or bur oak, black walnut, or tulip tree offer great potential for later timber harvest. The diverse forests of sycamore, ash, silver maple, and other species have great potential for wildlife, recreation, and high environmental quality.

The planting of new forests on mined lands can serve many of these same needs. Lessons from the past, however, are likely not immediately applicable to present mining practices. The Surface Mining Control and Reclamation Act of 1977 both sets goals for reclamation, and regulates the practices in overburden handling and land restoration. These practices differ in several ways from those of 30 years ago.

To achieve the goals of P.L. 95-87, we must focus our attention on several considerations:

1. In the Central States, trees on mined lands have proven to be a diverse, effective and permanent vegetative cover of the same seasonal variety native to the area and capable of self-regeneration.

2. At least 28 species of trees have already been shown to be successful candidates when properly used. Many more candidate species should be evaluated.

3. Surface mined lands vary greatly with respect to climate and soil conditions. Tree species selection must be matched to local planting conditions.

4. A planting program at least commensurate with the acreage of the forest land being mined will necessitate a yearly supply of millions of tree seedlings and seed of many different species. New sources will need to be developed.

5. Due to the grading requirements of P.L. 95-87, the regular use of tree-planting machines is now feasible. New successful and efficient planting methods will sustain an interest in using trees rather than encouraging the conversion of forest land to other uses.

6. It seems possible that considerable grading may actually be detrimental to many desired species of trees. Both soil properties and tree response should be studied to understand better the role of grading in tree establishment and growth to maturity.

7. Successful combinations of ground cover for erosion control and of desirable tree species must be established for each reclamation region or area.

The keys to achieving the goals of P.L. 95-87 are, then, building on the lessons of the past and developing new understanding for the future. Successful reforestation requires much thought and effort before the trees ever go into the ground. And without continued experimentation, we shall deprive ourselves of the full benefits trees can bring to reclaimed areas.

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