Growth of Hardwoods and Conifers After 47 Years on Coal Mine Soils in Southern Illinois

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Survival, height, and DBH are reported for 18 tree species planted chiefly in 1947 by the USDA Forest Service on lands surface-mined for coal in southern Illinois. Species with the best overall performance among 16 species planted in plots by row were black walnut (Juglans nigra *L.) planted as seedlings or seed, sweetgum* (Liquidambar styraciflua *L.), and tuliptree (yellow-poplar)* (Liriodendron tulipifera *L.). Conifers performed poorly except on extremely acidic sites. Tuliptree, silver maple* (Acer saccharinum *L.), and white and red oak* (Quercus alba *L. and* Q. rubra *L.) planted in single-species stands grew well.* Tree Planters' Notes 47(1):24-29; 1996.

Systematic study of tree growth on lands in the Midwest that were surface-mined for coal was begun by the USDA Forest Service in the years following World War II. The Forest Service's Central States Experiment Station, under the leadership of Dr. Arthur G. Chapman, first carried out an inventory of mined lands. Several series of plots were then established, usually with both hardwoods and conifers, from Ohio to Oklahoma on mined lands with differing topography, soils, and presence of overstory trees. The plots have well-documented planting plans that include soil conditions and other factors affecting tree performance (tables 1 and 2).

Eight hardwood and 8 conifer species were planted on plots in Illinois in 1947. Early tree survival and height growth were followed closely. Results after 10 to 12 years were reported for Illinois by Boyce and Neebe (1959) and by Limstrom (1960) for the entire Midwest in an able summary of the factors affecting successful reclamation with trees on mined land. Fifteen-year data were reported for 2 sets of plots in southern Illinois by Ashby and Baker (1968).

In 1976, the Forest Service funded re-measurements of remaining tree plantings on mined lands in the Midwest. Forest canopies of planted and volunteer trees had developed with examples of good to excellent growth by regionally adapted tree species in Kansas, Missouri, Indiana, and Illinois (Ashby and others 1980) and in Ohio (Larson and Vimmerstedt 1983). Volunteer trees were numerous (Ashby and others 1981); typically on the southern Illinois sites, hackberry/sugarberry and black cherry were characteristic of mesic sites. Coarse fragments in the spoil had weathered, A1 horizons darkened by organic matter were present, and extremely acidic soils had become less acidic on plots both included and not included in this paper (Davidson and others 1988). Pieces of siltstone had been penetrated by fine roots and often could be broken by hand.

In Illinois, diameter at breast height (DBH) was measured on all trees, and heights of commercially important species were measured for 5 to 10 representative trees/plot (Ashby and Kolar 1997). Some plots had been lost to landfills, housing developments, or re-mining by 1976, and still more by 1993. Several coal-company single-species block plantings with known planting dates were also measured in 1976. Before World War II, a coal company association in Illinois, under an agreement with the Illinois Division of Forestry, voluntarily planted an acre of trees for each acre mined.

In 1993, the 10 remaining Forest Service plots in southern Illinois along with 4 coal company block plantings were re-measured. Measurements were not postponed to age 50 because additional plots were threatened by a highway relocation following mine closure. The chief objective was to determine species performance in the several plantings.

Materials and Methods

Physical and chemical properties of each site, along with the abbreviations used in the text to identify each site, are listed in table 1. The rooting medium on all sites was a mixture of soil fines and coarse fragments from the overburden overlying the coal prior to mining. Overburden cast into spoil banks was the kind of rooting medium typical of mined sites prior to the passage of state laws and a 1977 federal law. The post-mining soils at 3 sites— RA, PEBL, and PESP— are mapped in recent county soil surveys as the Lenzburg Series, "well drained and moderately well drained, moderately slowly permeable soils on the sides and crests of spoil banks and on graded slopes in surface-mined areas in the uplands. These soils formed in fineearth material that is mainly a mixture of calcareous loamy till and weathered siltstone. Rock fragments of siltstone and limestone are common" (Miles 1988). The post-mining soils at sites— SAEA and SADP— are mapped as Orthents in an older soil survey.

Table 2—*Common and scientific names of species in the text*

Common name	Scientific name
Silver maple	*Acer saccharinum* L.
Hackberry/sugarberry	*Celtis occidentalis* L./*C. laevigata* Willd.
Flowering dogwood	*Cornus florida* L.
Autumn olive	*Elaeagnus umbellata* Thunb.
Ash, white	*Fraxinus americana* L.
Black walnut	*Juglans nigra* L.
Redcedar, eastern	*Juniperus virginiana* L.
Sweetgum	*Liquidambar styraciflua* L.
Tuliptree or yellow-poplar	*Liriodendron tulipifera* L.
Japanese honeysuckle	*Lonicera japonica* Thunb.
Osage-orange	*Maclura pomifera* (Raf.) Schneid.
Locust borer	*Megacyllene robiniae* (Forst.)
Pine, jack	*Pinus banksiana* Lamb.
shortleaf	*P. echinata* Mill.
red	*P. resinosa* Ait.
pitch	*P. rigida* Mill.
loblolly	*P. taeda* L.
eastern white	*P. strobus* L.
Virginia	*P. virginiana* Mill.
Cottonwood, eastern	*Populus deltoides* Bartr. ex Marsh.
Black cherry	*Prunus serotina* Ehrh.
Oak, white	*Quercus alba* L.
Northern red	*Q. rubra* L.
Shumard	*Q. shumardii* Buckl.
Black locust	*Robinia pseudoacacia* L.

Sites RA, PEBL, and PESP had typical pre-law spoil banks and were slightly alkaline (table 1). Site SADP minesoils were slightly acidic and relatively level after dragline pullback in tandem mining with a power shovel. Site SAEA had extremely acidic spoil banks with relatively low extractable K. Levels of extractable P were low on all sites (table 1). The sites when planted had varied kinds and amounts of volunteer herbaceous cover, and occasional cottonwood (see table 2 for scientific and common names) or other volunteer pioneer trees.

The statistical design of the 1947 Forest Service plantings at each site in Illinois was 17 completely randomized rows in each of 2 adjacent blocks (plots). Each randomly assigned row had 50 trees of a single species. Tree rows ran up and down slope at right angles to the ridge-and-valley topography commonly present. All trees were planted as bareroot nursery stock with a planting bar (dibble) on a 2.1-m (7-ft) spacing within a row and between rows. Seedlings were not planted in the occasional low-lying areas or died from later flooding/siltation. No ground cover was planted on any of the sites nor were management treatments given.

Sites RA, SAEA, and SADP were planted in spring 1947 to 16 species— 8 hardwoods and 8 conifers. A second randomized row per plot of black walnut was planted as seed, 2 nuts to a planting spot for a total of 17 rows. The same 8 hardwoods (9 randomized rows of 50 trees each) and no pines were underplanted in 2 stands of 10-year-old trees planted in 1938. Site PEBL had a stand of black locust and PESP of shortleaf pine. Both overstory stands largely broke up between about 1955 and 1965 (Ashby and others 1966).

In 1993, we measured the DBH of all planted trees in the remaining Forest Service plots. Heights were measured with a Haga altimeter for all trees in a row if 10 or fewer survived. Sites with more than 10 trees/row had a minimum of 20 tree heights measured /species.

Heights were taken on 71 % of all trees. Height and DBH data were described using several statistical measures and analyzed using an ABSTAT program for ANOVA on an IBM PC. Statistically significant differences in mean heights and DBH's were evaluated at the " = 0.05 level between major hardwood species and between the several sites.

Four single-species block plantings with 2.1-m (7-ft) spacing near sites SADP and SAEA on Sahara Mine No. 6 in Saline County also were measured. Tuliptree had been underplanted in a decadent 16-year-old black locust stand by the Forest Service in 1954. Somewhat older plantations of silver maple, white oak, or red/Shumard oak had been planted by the coal company association. The rows of the plantings paralleled the ridges with 4 rows each of approximately 15 trees in the tuliptree and of 30 trees in the white oak. The silver maple and red/Shumard oak plantings were larger. All of the tuliptree and 65 or more trees of the other species were measured. Standard deviations of the means and coefficients of variation were computed.

Results

Percentage survival varied greatly among planting sites, among species within a site, and for a species from site to site (table 3). Except for tuliptree and Osage-orange on the PESP site, survival was less than 50% (1,100 trees/ha or 444 trees/ac). Only black walnut planted as seedlings and as seed were found on both plots of all sites 47 years after planting. Smaller, volunteer walnuts were also found. Species with low survival were often found only on one plot of a site. Some species measured in 1976 were not found in 1993 (table 3).

Survival of the pines and of sweetgum, silver maple, and ash was greatest on the extremely acidic SAEA site. Only shortleaf and Virginia pine survived on all 3 sites where planted. Survival was greater for hardwoods underplanted in the pine (PESP) than in the locust (PEBL) stand, except for silver maple with no trees in PESP Percentage survival on SAEA and SADP is underestimated because parts of some rows of plots on those sites had been bulldozed during road construction.

Among the major hardwoods (not including Osage-orange) mean tree heights after 47 years ranged from 13 m (43 ft) for white ash to 28 m (93 ft) for tuliptree and sweetgum (table 4). Tuliptree and black walnut from seed had greater height at all ages where underplanted in the black locust (PEBL) than in the shortleaf pine (PESP) stand (figure 1). Height growth of the conifers and some hardwoods was greatest on the extremely acidic site SAEA. Heights of pines ranged from 21 m (70 ft) for eastern white to 27 m (90 ft) for loblolly.

The lowest DBH among the major hardwoods was 16 cm (6 in) for sweetgum underplanted in shortleaf pine (PESP). The greatest DBH was 36 cm (14 in) for black walnut, tuliptree, and loblolly pine (table 4).

Table 3—*Percentage survival after 47 years of 100 trees/species each planted by the USDA Forest Service in 1947 on 5 sites in 3 counties of southern Illinois (no pines were planted experimentally in Perry County)*

	Saline Co.		Randolph Co.	Perry Co.	
Species	SAEA	SADP	RA	PESP	PEBL
All trees	16	12	8	29	12
Silver maple	21	6	0	0*	10
White ash	4	0*	0*	0*	0*
Black walnut (seedling)	7	21	31	36	26
Black walnut (seed)	15	29	27	20	8
Sweetgum	44	29	11	38	0*
Tuliptree	9	5	0	55	15†
Osage-orange	21	32	32	56	21
Redcedar, eastern	3	14‡	1		
Pine, shortleaf	8	5	3		
Pine, pitch	5	0*	0*		
Pine, loblolly	30	9	0*		
Pine, eastern white	23	0	0		
Pine, Virginia	16	3	1		

* Present in 1976 (30 years old). Jack and red pine also survived until age 30 and not to age 47. Planted cottonwood and black locust could not be distinguished from volunteers among scattered trees present in the plots.
† Extensive bark damage noted at age 15 years, with later mortality.
‡ A row on the border and next to osage-orange had relatively high survival in 1 plot.

Table 4—*Mean height and diameter at breast height (DBH) with standard errors by site 47 years after planting*

	Saline Co.		Randolph Co.	Perry Co.	
Species	SAEA	SADP	RA	PESP	PEBL
Mean height (m)					
All species (71% of trees)	21±1	23±1	20±1	17±6	23±1
Silver maple	19±2	22±1	—	—	22±2
White ash	13±4	—	—	—	—
Black walnut	20±3	27±2	24±1	20±1	27±1
Black walnut seed	17±2	24±2	27±1	19±1	25±3
Sweetgum	28±1	26±1	18±1	14±1	—
Tuliptree	28±1	27±5	—	22±1	26±1
Osage-orange	9±1	15±1	14±1	10±1	14±2
Redcedar, eastern	17±2	10±1	12±0		
Pine, shortleaf	23±2	20±2	13±1		
Pine, pitch	22±2	—	—		
Pine, loblolly	27±1	24±1	—		
Pine, eastern white	21±1	—	—		
Pine, Virginia	23±1	23±0	10±1		
Diameter at breast height (cm)					
All species (100% of trees)	28±1	26±1	29±1	17±1	27±1
Silver maple	25±2	23±1	—	—	27±3
White ash	17±2	—	—	—	—
Black walnut	22±4	28±2	36±2	21±1	32±2
Black walnut seed	20±2	26±2	34±2	18±2	25±3
Sweetgum	33±1	30±2	25±2	16±1	—
Tuliptree	33±2	36±7	—	21±1	34±3
Osage-orange	10±1	20±2	20±2	9±1	15±2
Redcedar, eastern	23±3	14±1	22±0		
Pine, shortleaf	24±2	28±3	27±2		
Pine, pitch	30±3	—	—		
Pine, loblolly	36±1	41±2	—		
Pine, eastern white	29±3	—	—		
Pine, Virginia	32±2	29±5	21±0		

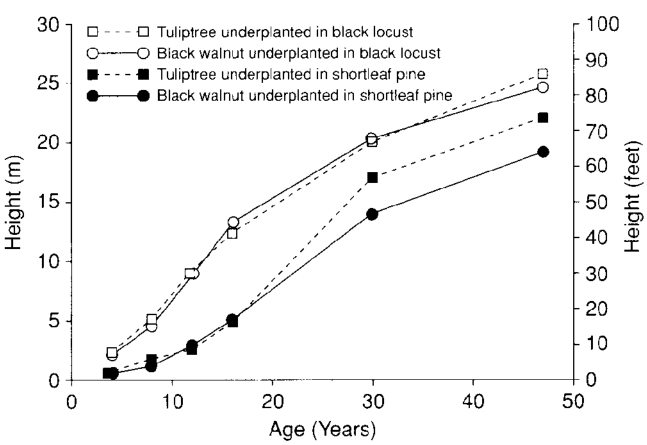

Figure 1—*Tree heights at 6 ages of tuliptree and of black walnut from seed underplanted in 10-year-old stands of black locust (PEBL) or shortleaf pine (PESP).*

Differences of height or DBH were not statistically significant between the tallest hardwood species or for walnut seedlings versus seed (table 5). Walnut and tuliptree comparisons related to overstory (PEBL vs. PESP) were significantly different. No sweetgum survived on the PEBL overstory site to be compared. Comparisons between sites based on all trees were significantly different for height and for DBH if one site was PESP, and for 2 other comparisons of height.

Trees in the block plantings generally looked to be in excellent condition. Mean heights ranged from 25 to 33 m (81 to 109 ft) (table 6). The DBH's tended to be about 1 % of the height. Coefficients of variation were higher for DBH than for height. In the red/Shumard oak plantation, northern red oaks were typically smaller than Shumard oaks. Exact numbers of each were not determined because identification was painstakingly slow and not always certain.

Table 5—*Statistical probability of equally large differences due to chance in a comparison of mean height and diameter at breast height (DBH) for species, species and overstory, and all trees by site.*

	Probability	
	Height	DBH
Species		
All sweetgum* vs. all walnut*	0.52	0.74
All tuliptree* vs. all walnut	0.11	0.35
Sweetgum vs. tuliptree	0.07	0.58
Black walnut seedling vs. seed	0.24	0.06
Species by overstory		
Walnut under locust vs. under pine	0.00	0.00
Tuliptree under locust vs. under pine	0.04	0.00
All trees by site		
RA versus PEBL	0.07	0.16
RA versus PESP	0.00	0.00
RA versus SAEA	0.47	0.20
RA versus SADP	0.01	0.30
PEBL versus PESP	0.00	0.00
SAEA versus SADP	0.04	0.94

* The coefficients of variation for mean height and DBH, respectively, were 28 and 39% for black walnut, 31 and 39% for sweetgum, and 24 and 47% for tuliptree.

Discussion

Species performance varied from site to site in a manner analogous to differences in forest types on nonmined sites (Burns and Honkala 1990). For example pines persisted and grew best on the extremely acidic site SAEA. Another site lost to a county landfill after 1976 had the best growth of pitch, red, and white pine on an extremely acidic soil, pH 4.3 in 1947 and 4.8 in 1976.

Roughly 15 to 20% dead or missing tuliptrees were observed in the Saline Co. block planting in the period from 1976 to 1993, evidently from natural self-thinning. Volunteer black cherry, white oak (from the adjacent planting), flowering dogwood, and other trees, as well as the exotic shrub invaders Japanese honeysuckle and autumn olive, and also woodland herbs were noted in 1993. Dead silver maples or white oaks were not recorded in 1976 or 1993, or dead red/Shumard oaks in 1976. By 1993 beaver damage was recorded on 46% of the living red/Shumard trees measured and 6 trees near a pond were dead. Essentially no volunteer trees were invading the stand of red/Shumard oak, with a few observed in the white oak and silver maple stands.

Pre-mining soils on the present study sites mapped in local county soil reports commonly had subsoils that restricted movement of air and water and growth of roots. Their suitability for growing black walnut was evaluated by Voss and Howerton (1980) using criteria of drainage, soil depth, texture, percentage of coarse fragments, pH of subsoil, and slope. Almost all were shown as unsuited or of questionable suitability. Only limited areas, such as along stream terraces, have suitable soils. Federal and state laws and regulations in the Midwest now require replacement of typical pre-mining soils after mining.

In contrast to performance on typical pre-mining soils, heights of black walnut at age 47 on Forest Service sites PEBL, RA, and SADP were greater than the highest reported site index (SI) age 50 for Central States plantations (Carmean and others 1989). The dragline pullback SADP relatively level site with good growth of several species was much less compacted than present-day sites replaced and graded with pan scrapers and bulldozers.

Two 45-year-old Forest Service sites with stony spoils in east-central Ohio had 42% white ash survival in 1992, 21 % white pine, and 16% tuliptree (Zeleznik and others 1993). The tuliptree heights were lower than those on the Illinois sites with no significant height differences among these three species.

Findings from tree plantings on post-mining soils help identify factors— pH, bulk density, and coarse fragments— that can reveal new understanding of tree growth. Contrary to conventional wisdom, for example, a site with extremely acidic soil gave superior growth of several hardwood and conifer species. Fresh minerals from weathering of the overburden spoil likely offset the kind of mineral nutrition problems associated with extreme acidity on other soils

Table 6—*Soil pH in 1976 and age, number measured, mean heights, and diameters at breast height (DBH) with standard errors and coefficients of variation (CoV) of single-species block plantings in Saline County*

Species	pH 1976	Age (yrs)	No.	Height (m)	CoV (%)	DBH (cm)	CoV (%)
Oak, white	5.8	55	65	26±3	13	23±1	42
Oak, red/Shumard	7.2	55	65	33±3	8	35±1	37
Maple, silver*	6.7	51	100	25±4	19	26±1	24
Tuliptree†	5.7	40	49	30±3	11	30±1	22

* The mean number of stems was 1.75±1, range 1 to 5, and CoV 50%.
† Planted in a decadent black locust stand.

Conclusions

Mine soils or spoils planted before the passage of federal and state laws were highly suited for growth of forest trees. There are thousands of acres of similar pre-law mined land in the lower Midwest. With proper species selection and management, these mined lands in southern Illinois would be a valuable resource for production of silver maple, black walnut, sweetgum, tuliptree, and white and red /Shumard oaks. Areas with extremely acidic soils are limited and had excellent growth of sweetgum and tuliptree, and of loblolly pine. Other pines also survived and grew best on acidic soils. Osage-orange performed very well as a companion species.

Results with the several types of management in the present study have important implications. Black walnut grew well as seedlings or seed in mixed row plantings. Several other species planted in blocks survived and grew exceptionally well. A shortleaf pine overstory (PESP) gave overall good survival and poor growth of underplanted hardwoods, while a black locust overstory (PEEL) gave the reverse. A site relatively leveled (SADP) by dragline pullback had overall good growth of the surviving species. With minimal grading to avoid compaction, mined lands can be productive sites for tree growth with easier access for management and cosmetic features attractive to the public.

Better soils from mining to replace the presently widespread natural soils with limiting conditions for plant growth including fragipans, claypans, and subsoil compaction would bring long-term benefits to areas similar to our study areas.

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