Liriodendron Seedling Growth on Calcareous and Acid Minesoils Developed under Pine or Hardwood[1]

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Abstract.--We tested effects of two parent materials, two slope positions, and four tree species on growth and mineral nutrition of tuliptree seedlings. We grew the seedlings for 17 weeks in cores of acid (pH 3.7) or calcareous (pH 7.2) minesoil collected under white pine (*Pinus strobus* L.), black locust (*Robinia pseudoacacia* L.), white ash (*Fraxinus americana* L.), or tuliptree (*Liriodendron tulipifera* L.) that had been planted by the U.S. Forest Service in 1946 on ungraded, unfertilized coal spoils. In 1977, we collected cores of soil near the top or bottom of the small, steep-sided hillocks and planted tuliptree seedlings in these cores. Seedlings grown in black locust soils were taller, with heavier leaves, stems and root systems than those grown in other minesoils, while seedlings grown in white pine soils were smaller and lighter than all the others. Effect of slope position depended on parent material; on the acid minesoil, seedlings grown in soil from the lower slope position were taller, with heavier leaves and root systems, but on the calcareous minesoil, slope position had the opposite effect. The acid minesoil produced larger, heavier seedlings than the calcareous one. Black locust soils produced seedlings with leaf blades higher in N and P and lower in Mg than those developed under the other 3 species. Leaf blades of seedlings grown in white pine soils were lowest in P and K. Seedlings grown in acid minesoil had higher concentrations of N, P, K, Mg. and Mn, and lower concentrations of Ca in their leaf blades than those grown in calcareous minesoil. Possible reasons for difference in seedling growth include more favorable physical properties in the acid minesoil or micronutrient deficiciencies in the calcareous minesoil.

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[1]Paper presented at the 1988 Mine Drainage and Surface Mine Reclamation Conference sponsored by the American Society for Surface Mining and Reclamation and the U.S. Department of the Interior (Bureau of Mines and Office of Surface Mining Reclamation and Enforcement), April 17-22, 1988, Pittsburgh, PA

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Proceedings America Society of Mining and Reclamation, 1988 pp 74-78
DOI: 10.21000/JASMR88020074
https://doi.org/10.21000/JASMR88020074

INTRODUCTION

As coal production by surface mining increased during World War II, miners and conservation agencies recognized the need for reclaiming coal spoils to restore productivity and to reduce off-site damages. In 1946 the U.S. Forest Service, in cooperation with several coal companies, established a number of experimental plantings throughout the eastern Ohio coal fields (Limstrom and Merz, 1949; Finn, 1958; Limstrom, 1960; Larson and Vimmerstedt, 1983). White pine, black locust, tuliptree and white ash were among the species planted at 7 x 7 foot spacings in 105 x 105 foot blocks on both calcareous and acid minesoils. Thirty-one years later, we compared growth and mineral nutrition of tuliptree seedlings planted in soils that had developed under these four species on the two contrasting parent materials (Jewell, 1978). We also tested the effect of slope position by growing the seedlings in soil collected from the top or bottom of the ungraded spoil banks. Our objectives in this greenhouse experiment were to determine the effects of the following soil-forming factors: parent material, organisms and topography, on growth and mineral nutrition of tuliptree seedlings. In particular, we wanted to find out how tuliptree seedlings performed on soil developed under black locust because of the large acreage of coal spoils revegetated with black locust that were subsequently attacked and rendered unproductive by locust borer (Megacyllene robiniae).

MATERIALS AND METHODS

In this study we used undisturbed cores of soil obtained by forcing number 10 tin cans into the soil until the can was flush with the top of the litter, as described by Clark (1963). Cans were excavated and removed to a greenhouse. Plantings from which cores were removed were on ungraded, unlimed and unfertilized minesoils created by surface mining from 1941 to 1944.

Calcareous minesoils near Cadiz, Ohio were produced in 1943-44 by shovel stripping the Pittsburgh coal seam. Overburden consisted of acidic shale, calcareous shale, and limestone, with limestone predominating. Upon disintegration and settling, these materials formed tight, impervious, poorly aerated spoil banks (Limstrom, 1946a) which are presently classified as Morristown stony clay loam, a loamy-skeletal, mixed calcareous, mesic Typic Udorthent (Rubel et al., 1981). At planting these minesoils were 90% barren, with scattered plants of red clover (Trifolium pratense), wild carrot (Daucus carota), common plantain (Plantago spp.), thistle, pepperweed (Lepidium spp.), bluegrass (Poa spp.), sweetclover (Melilotus spp.), dandelion (Taraxacum), elderberry (Sambucus spp.) and dead ragweed (Ambrosia bidentata) (Limstrom, 1946a). In 1976, pH of this soil averaged 7.1, with 69% of the soil particles less than 2.0 mm in diameter.

Acid minesoils south of Dundee, Ohio were produced in 1941-42 by mining the Lower Kittanning coal seam. Grayish black shale predominated in the overburden, with some sandstone. Minesoil at this site is classified as Bethesda silty clay loam, a loamy-skeletal, mixed acid Typic Udorthent (L. A. Tornes, Assistant State Soil Scientist, U.S.D.A. Soil Conservation Service, personal communication). At planting time, the spoil surface varied from shaly sand to stony sand, with soil pH ranging from 3.8 to 5.5, and with little or no natural vegetation (Limstrom, 1946b). In 1976, soil pH averaged 3.7, with 61 percent of the soil particles less than 2.0 mm in diameter.

On each parent material, we randomly selected 3 trees of each species growing on upper and lower slope positions. Soil cores were removed under each tree in the 4 sectors midway between the trunk and the edge of the crown. With 2 parent materials, 4 tree species, 2 slope positions, 3 trees per slope position and 4 cores per tree, a total of 192 cores were involved in the experiment. Soil cores, with plastic film at the bottom to prevent free drainage, were arranged in the greenhouse in a completely randomized design, and re-randomized half way through the experiment.

Two newly-germinated tuliptree seedlings were transplanted into each core on May 16 and grown under natural light until September 7. Cores were watered every third day with deionized water; the amount was adjusted periodically by weighing randomly-selected cores and estimating the amount of water required to restore them to their weight at time of collection.

At harvest, we measured total seedling height from cotyledon to tip of terminal bud. Leaves were counted and leaf blades, petioles and stems of each seedling were dried for 3 days at 60° C. Roots of the seedlings were washed free of soil and also dried at 60° C. Dry weights of seedling parts were determined.

Nitrogen concentration in leaf blades was determined by Kjeldahl analysis, and P, K, Ca, Mg and Mn were determined by inductively coupled plasma emission spectrometry. We combined plant tissue from the two upslope and two downslope soil cores (4 seedlings) in order to have sufficient material for tissue analysis.

Data subjected to analysis of variance included seedling heights, weights of leaf blades, leaf petioles, stems and roots, number of leaves per seedling and concencration of N, P, K, Ca, Mg and Mn in leaf blades. Means of the physical measurements of the two seedlings in each core were used as data entries in the statistical analysis. When analysis of variance showed statistically significant effects at $p=0.05$, Duncan's mean range test was used for mean separation.

RESULTS

Tuliptree seedlings grown in soils collected under black locust were taller, heavier and had more leaves than those grown in soils from under tuliptree, white ash or white pine. Seedlings grown on white pine soils were smallest (table 1). The effect of slope position on seedling size varied with parent material. On the acid minesoil, soils from the lower slope positions produced the tallest, heaviest seedlings but on the calcareous minesoils, soils from the upper slope positions had the tallest, heaviest seedlings (table 1). In the case of stem weight, the

Table 1.--Height, number of leaves, petiole, blade, stem and root weights of tuliptree seedlings grown for 17 weeks in undisturbed soil cores collected at upper or lower slope positions under 4 tree species on acid or calcareous minesoils.

	Total Height	Total	Blades	Oven Dry Weight Petioles	Stem	Root
Species[1/]	(cm)	(no)	g			
Black Locust	15.3[a]	10.2[a]	1.19[a]	0.15[a]	0.73[a]	2.03[a]
Tuliptree	12.6[b]	9.0[b]	0.95[b]	0.12[b]	0.59[b]	1.93[a]
White Ash	11.7[bc]	8.6[b]	0.85[bc]	0.10[bc]	0.50[bc]	1.92[a]
White Pine	10.3[c]	8.5[b]	0.74[c]	0.09[c]	0.43[c]	1.58[b]
Parent Material x Slope Position Interaction						
Acid						
Upper Slope	12.76[b]	9.4[ab]	0.96[b]	0.12[b]	0.59[b]	1.89[b]
Lower Slope	17.06[a]	9.8[a]	1.26[a]	0.16[a]	0.81[a]	2.42[a]
Calcareous						
Upper Slope	11.07[b]	8.8[bc]	0.86[b]	0.10[b]	0.50[b]	1.76[b]
Lower Slope	8.94[c]	8.3[c]	0.64[c]	0.08[c]	0.35[c]	1.39[c]

[1/]Within each column, means with a common superscript letter do not differ significantly at the 5% level, Duncan's Mean Range Test.

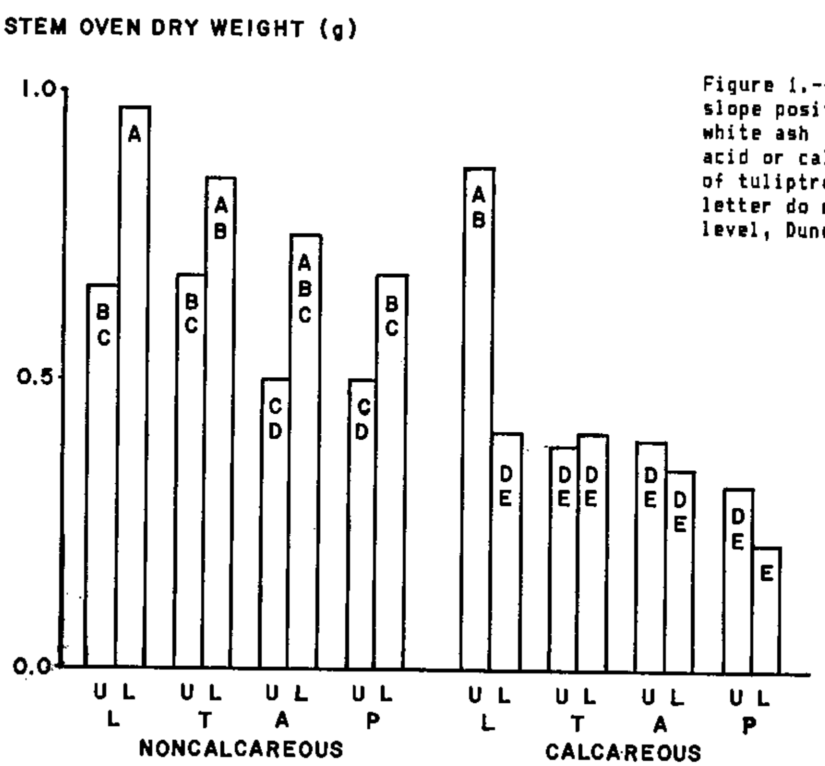

Figure 1.--Interaction of upper (U) or lower (L) slope positions, black locust (L), tuliptree (T), white ash (A) or white pine (P) tree species and acid or calcareous parent material on stem weight of tuliptree seedlings. Bars containing a common letter do not differ significantly at the 5% level, Duncan's Mean Range Test.

Table 2.--Concentrations of N, P, K, Ca, Mg and Mn in leaf blades of tuliptree seedlings grown for 17 weeks in undisturbed soil cores collected at upper or lower slope positions under 4 tree species on acid or calcareous minesoil.

	N	P	K	Ca	Mg	Mn
	%					ppm
Species[1/]						
Black Locust	1.91[a]	0.22[a]	1.50[a]	1.23	0.28[b]	405
Tuliptree	1.49[b]	0.19[b]	1.49[a]	1.36	0.37[a]	378
White Ash	1.51[b]	0.19[b]	1.53[a]	1.34	0.38[a]	352
White Pine	1.50[b]	0.17[c]	1.28[b]	1.42	0.37[a]	388
Parent Material[1/]						
Acid	1.66[a]	0.22[a]	1.57[a]	1.00[b]	0.38[a]	729[a]
Calcareous	1.54[b]	0.17[b]	1.33[b]	1.67[a]	0.33[b]	32[b]

[1/]Within each column, means with a common superscript letter do not differ significantly at the 5% level, Duncan's Mean Range Test.

Table 3.--Interaction of tree species and parent material on potassium concentrations in leaf blades of tuliptree seedlings grown for 17 weeks in undisturbed cores of eastern Ohio minesoils.

	Parent Material	
	Acid	Calcareous
	Potassium Concentration (%)	
Species[1/]		
Black locust	1.56[bc]	1.45[cd]
Tuliptree	1.69[ab]	1.28[de]
White Ash	1.80[a]	1.26[de]
White Pine	1.23[e]	1.32[de]

[1/]Means with a common superscript letter do not differ significantly at the 5% level according to Duncan's Mean Range Test.

species x slope position x parent material interaction was significant (figure 1). Stem weights of seedlings from upper slope, calcareous soils under black locust differed from all others grown on calcareous soils and were almost as heavy as the heaviest grown on acid soils.

Nitrogen and phosphorus concentrations in leaf blades of seedlings grown in black locust soils were higher than in those from tuliptree, white ash or white pine, while magnesium concentrations were lower (table 2). Concentrations of P were lowest in leaf blades of seedlings grown in white pine soil. Concentrations of N, P, K, Mg and Mn were higher in leaf blades of seedlings grown on the acid soils; Ca concentrations were lower (table 2). There was a significant species x parent material interaction on potassium concentration of leaf blades, with those grown on soils from under tuliptree or white ash higher in the acid spoils than in the calcareous ones, while potassium concentrations did not differ significantly with parent material on locust or pine soils.

DISCUSSION AND CONCLUSIONS

Tuliptree is a demanding species in terms of nutrient requirements. If we consider tuliptree seedling growth to be a bioassay of soil quality, then we conclude that black locust was the most effective tree species for improving soil conditions on these ungraded, unfertilized coal spoils, and that white pine was least effective. Reasons for superiority of soils developed under black locust appear to be availability of nitrogen and phosphorus, with nitrogen availability probably the overriding factor. In a related study, soils that developed under black locust were higher in total nitrogen than those that developed under tuliptree, white ash, or white pine (Vimmerstedt et al., in press).

Of the two parent materials, the acid shales and sandstones produced larger, more nutrient-rich seedlings than the limestone. Availability of N, P and K was evidently greater in the acid minesoils, but the friable nature of the shale-derived soils, contrasted to the impervious nature of the calcareous soils, may have been an additional factor promoting greater growth on the acid parent materials. At the high pH of the calcareous minesoil, micronutrient deficiencies are an additional possible explanation for the relatively poor growth.

Because of its rapid early growth, nitrogen-fixing ability and potential for yielding valuable posts and poles, black locust was a popular early choice for reforesting coal spoils. Although locust borer attacks prevented growth of saleable products, black locust plantings were effective in soil improvement, and have paved the way for establishment of productive stands of succeeding species. Furthermore, more volunteer trees were found in black locust plantings than in those of white ash, white pine or tuliptree (Larson, 1984). White pine, although quite effective in producing a protective litter layer, was the least effective of the four species in creating favorable soil conditions for growth of tuliptree seedlings.

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