NC-134
RP
copy 2

USDA FOREST SERVICE
RESEARCH PAPER NC-134

Hardwoods Planted In Old Fields Favored By Prior Tree Cover

WILLARD H. CARMEAN, F. BRYAN CLARK, ROBERT D. WILLIAMS & PETER R. HANNAH

NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

CONTENTS

North Central Forest Experiment Station
John H. Ohman, Director
Forest Service - U.S. Department of Agriculture
Folwell Avenue
St. Paul, Minnesota 55108

Manuscript approved for publication March 1, 1976

1976

HARDWOODS PLANTED IN OLD FIELDS

FAVORED BY PRIOR TREE COVER

Willard H. Carmean, F. Bryan Clark, Robert D. Williams, and Peter R. Hannah

Large areas of marginal farm land located in hilly parts of the Midwest have been abandoned since the turn of the century. Several species of pine grow rapidly when planted on such land (Limstrom 1963), but successful plantings of hardwoods are rare, even where deep, well drained soils are apparently well suited for hardwoods. Nevertheless, hardwoods such as yellow-poplar (*Liriodendron tulipifera* L.) sometimes naturally seed into young pine plantations on the better soils. These volunteer hardwoods commonly grow faster than pines on the better sites even though growth would have been poor if the hardwoods had been planted in the grassy cover present a few years following land abandonment.

We studied an abandoned field in southern Indiana to determine whether planted hardwood growth differed according to vegetation. We also wanted to determine if these growth differences were associated with differences in physical, chemical, and biological soil conditions. Our results reveal that growth of planted hardwoods is strikingly different for areas that had supported some kind of tree cover since abandonment. These growth differences were associated with foliar nitrogen, and with several physical, chemical, and biological soil factors. We attribute the striking growth differences to the combined effect of soil conditions that have been improved by many years of tree cover present on abandoned agricultural land.

We have already published several papers describing the pot culture and endomycorrhizal results of our studies. In this paper we give 16-year results from field-planted hardwoods, and also we relate our field results to our previously published results. In addition, we attempt to relate our research to research elsewhere so as to, hopefully, give some overall perspective and interpretation to the complex problem of hardwood tree growth on abandoned agricultural land.

THE STUDIES

The Study Area

Our study area is a large field abandoned in the mid-1930's located on the Paoli Experimental Forest within the Hoosier National Forest in Orange County, Indiana. When we began our studies in 1960, the field was bordered by a second-growth hardwood forest. The outer portions of the field were unevenly stocked with volunteer hardwood trees and shrubs; the inner portion was in the grassy, nonstocked stage of natural old-field succession. In 1937 shortleaf pine (*Pinus echinata* Mill.) had been planted on part of the nonstocked area, and black locust (*Robinia pseudoacacia* L.) had been planted on a few areas that were severely eroded.

Hardwoods were planted in 1960 on four areas having different vegetation (table 1): (1) a nonstocked area, and areas clearcut from (2) a fully stocked stand of volunteer trees and shrubs, (3) a 23-year-old shortleaf pine plantation, and (4) a 23-year-old black locust plantation. Soil conditions were studied in these four areas and also in the hardwood forest and in an area half stocked with volunteer trees and shrubs. Most of the study areas are within about 550 feet of each other and generally represent a transect extending from the nonstocked area to the hardwood forest. The locust area is about 790 feet from the other study areas.

The study plots are on a broad, gently rolling ridge; slopes range from 4 to 10 percent, and aspect is south and southeast. The soils are Zanesville and Tilsit silt loams (fine-silty, mixed, mesic Typic Fragiudalfs, and Typic Fragiudults, respectively) that have developed from loess deposits overlying residual sandstone and shale. These soils are similar except for depth to an underlying fragipan: the Tilsit fragipan begins at about 20 inches causing

Table 1.--*Description and plant composition of the six study areas in 1960*

Area	Tree age	Stand basal area	Species composition
	Years	*Ft²/acre*	
Hardwood forest	60 to 80	143	Oaks (*Quercus* spp.) Hickories (*Carya* spp.) Sugar maple (*Acer saccharum* Marsh.) White ash (*Fraxinus americana* L.)
Nonstocked area	--	--	Broomsedge (*Andropogon virginicus* L.) Poverty oatgrass (*Danthonia spicata* (L.) Beauv.) Goldenrod (*Solidago* spp.)
Half-stocked area	0 to 30	41	Sassafras (*Sassafras albidum* (Nutt.) Nees) Persimmon (*Diospyros virginiana* L.) Elm (*Ulmus americana* L.)
Fully stocked area	0 to 30	88	Same as half-stocked field
Shortleaf pine plantation	23	137	Shortleaf pine (*Pinus echinata* Mill.)
Black locust plantation	23	68	Black locust (*Robinia pseudoacacia* L.)

some restrictions in internal drainage; the Zanesville fragipan begins at about 33 inches, resulting in somewhat better internal drainage (table 2).

Field Plantings

In 1960, one plot was established on each of the four areas. Each plot was 50

Table 2.--*Soil descriptions for the six study areas*

Area	Soil type	Soil horizon	Depth	Sand	Silt	Clay	pH	P[1]	K[1]
			Inches	*Percent*	*Percent*	*Percent*		*p/m*	*p/m*
Natural hardwood forest	Zanesville silt loam integrade to Wellston	A1	0-3	10	65	25	5.9	2	83
		A2	3-6	12	65	23	5.8	2	75
		B1	6-8						
		B21	8-16	12	61	27			
		B22	16-34	17	51	32			
		[2]B23x	34+						
Nonstocked area	Tilsit silt loam	Ap	0-3	10	63	27	5.8	2	46
		Ap	3-6				5.8	2	29
		B1	6-14	8	54	38			
		B21	14-21						
		[2]B22x	21-26	14	52	34			
Half-stocked area	Tilsit silty clay loam intergrade to Zanesville	Ap	0-3	11	61	28	6.0	2	52
		Ap	3-5				5.8	2	37
		B1	5-13	11	57	32			
		B21	13-27	13	55	32			
		[2]B22x	27-47	11	53	36			
Fully stocked area	Tilsit silt loam	Ap	0-3	11	63	26	6.0	2	89
		Ap	3-6				5.8	2	60
		B1	6-11	10	58	32			
		B21	11-20	15	52	33			
		[2]B22x	20-42	11	56	33			
Shortleaf pine plantation	Zanesville silt loam	A1	0-2				6.6	2	66
		Ap	2-4	12	62	26	6.2	2	37
		B1	4-9						
		B21	9-14	10	60	30			
		B22	14-33	9	54	37			
		[2]B23x	33-42						
Black locust plantation	Zanesville silty clay loam (severely eroded) intergrade to Wellston	B1	0-3	12	59	29	5.6	5	83
		B1	3-4.5				5.3	2	52
		B21	4.5-9						
		B22	9-15	10	52	38			
		B23	15-22	12	54	34			
		[2]B24x	22-32						

[1]Tests for "readily available" P and K were made by the Purdue University Soil Testing Laboratory usin 0.75 N HCl--results are expressed on the elemental basis.
[2]Fragipan horizon is denoted by "x".

by 100 feet surrounded by a 35-foot isolation strip. All trees and shrubs were removed and stumps were treated with herbicide to reduce sprouting. On each plot we planted 50 1-0 seedlings each of red oak (*Quercus rubra* L.), black walnut (*Juglans nigra* L.), sweetgum (*Liquidambar styraciflua* L.), and yellow-poplar. Seedlings were planted in 5 randomly assigned rows of 10 seedlings each and spacing was 5 by 5 feet. Planted trees were released from competing brush and sprouts as necessary.

At the time of planting, broomsedge and poverty grass covered the nonstocked area. Little herbaceous growth developed on the other three areas in the first growing season following clearing and planting, but in subsequent years dense growth developed on plots in the fully stocked and shortleaf pine areas; herbaceous growth was especially dense in the black locust area.

Foliar samples were collected at 5, 10, and 16 years and were analyzed for nitrogen, phosphorus, and potassium.[1]

Soil Measurements

Soil profiles were described in 1962, and composite soil samples were collected for determining texture (Bouyoucos 1951), organic content (Walkley 1947), pH, and "readily available" phosphorus and potassium. For each area 5 to 15 undisturbed 21.2-in.^{3} soil cores collected at 1-to-4-inch, and the 9-to-12-inch depths for determing bulk density and noncapillary pore volume (Leamer and Shaw 1941).

Pot Culture Studies

To compare growth of field planted yellow-poplar seedlings with growth of seedlings grown in the laboratory we collected three undisturbed, 0.8-gallon soil cores from the surface six inches of each of the four planting areas. Soil cores also were collected from the adjacent hardwood forest, and the area half stocked with volunteer trees and shrubs. Several newly germinated yellow-poplar seeds were planted in each soil core. When seedlings were well established, they were thinned to three per core. After 12 weeks the seedlings were washed from the cores and weighed. Results of this study have been published (Clark 1964), but are included here for comparison.

We suspected that endomycorrhizae might affect phosphorus absorption and the growth of yellow-poplar seedlings. So we collected 18 additional undisturbed, 0.8-gallon surface soil cores from the mixed hardwood forest area. Half of them were sterilized using methyl bromide. We then applied one of three levels of phosphorus fertilizer (0, 66, and 132 lbs/acre elemental phosphorus) to each core. Newly germinated yellow-poplar seeds were planted in each core. When well established, they were thinned to three per core. After 15 weeks the two largest seedlings in each core were washed from the soil cores and weighed.

RESULTS

Height Growth

All planted hardwoods grew slowly for the first 2 years. At 5 years, however, differences in height growth among the four areas were evident, and at 10 and 16 years, height differences were striking (figs. 1, 2, and 3). Analysis of variance for significant height differences between areas was not possible because only a single plot was located in each of the four areas. However, average heights for each species were consistent as shown by small standard errors of the mean. Standard errors at 5, 10, and 16 years were usually less than 1, 2, and 3 feet, respectively.

All trees planted on the nonstocked area had slow growth, and at 10 years they were not much taller than when planted. Mortality for red oak and black walnut was severe on the nonstocked area, top dieback and resprouting were common, and by 16 years all the oak and walnut were dead. Sweetgum and yellow-poplar survived much better on the nonstocked field, but growth was also slow for the first 10 years after planting. However, after 10 years, annual height growth

[1] *On each area several healthy leaves were collected from the upper crown of at least 10 sample trees in late August; leaves were dried at 68° C for 24 hours, petioles were removed, and leaves were ground in a Wiley Mill. Foliar analyses of 5-year samples were made by the Iowa State Soil Testing Laboratory, 10-year samples were analyzed by the Ohio Agricultural Research and Development Center, and 16-year samples were done by the University of Minnesota Soil Science Research Analytical Laboratory.*

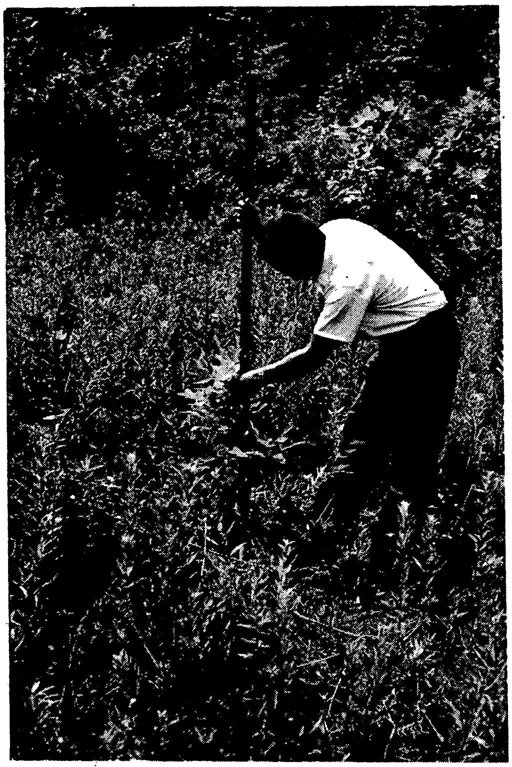

Figure 1.--*These yellow-poplar on the nonstocked area were not much taller after 6 years than they were when planted.*

Figure 2.--*These yellow-poplar on the locust area averaged almost 20 feet in height 7 years after planting.*

for sweetgum and yellow-poplar was much better on the nonstocked area. At 16 years annual height for sweetgum on the nonstocked area averaged about 1.8 feet per year while, in contrast, sweetgum planted on the pine, fully stocked, and locust areas averaged about 2.2, 2.6, and 2.8 feet per year, respectively (fig. 4).

Growth of sweetgum and yellow-poplar was much better on the plots clearcut from the fully stocked and pine areas, and growth was outstanding on the plot clearcut from the black locust plantation.[2] At 10 years sweetgum and yellow-poplar planted on the locust area were 17.7 and 28.0 feet taller, respectively, than they were on the nonstocked area; at 16 years they were 22.9 and 37.5 feet taller than on the nonstocked area. The outstanding 16-year height of sweetgum and yellow-poplar in the locust area was mostly due to exceptionally rapid growth from 5 to 10 years when trees grew 3 to 4 feet in height each year. But after the 10th year, annual height growth of both sweetgum and yellow-poplar in the locust area was somewhat slower, and was similar to growth in the fully stocked and pine areas.

Growth of red oak and black walnut also was better in the locust area than in the other areas. However, after the 10th year, annual height growth of oak and walnut in the locust area slowed somewhat, just as did yellow-poplar and sweetgum growth in the locust area.

Foliar Nitrogen

Foliar nitrogen for the four species differed greatly on the four areas (fig. 5).

[2]*An additional plot was established 2 years earlier in a somewhat less eroded portion of this same locust plantation. Rapid growth of planted trees on this older plot was similar to growth on the locust area (fig. 3), but data could not be statistically combined with those used in the current analysis. After 18 years the four tallest red oak in each of the five rows averaged 19.3 ± 2.8, black walnut 29.4 ± 3.3, sweetgum 37.0 ± 0.9, and yellow-poplar 48.8 ± 1.9 feet.*

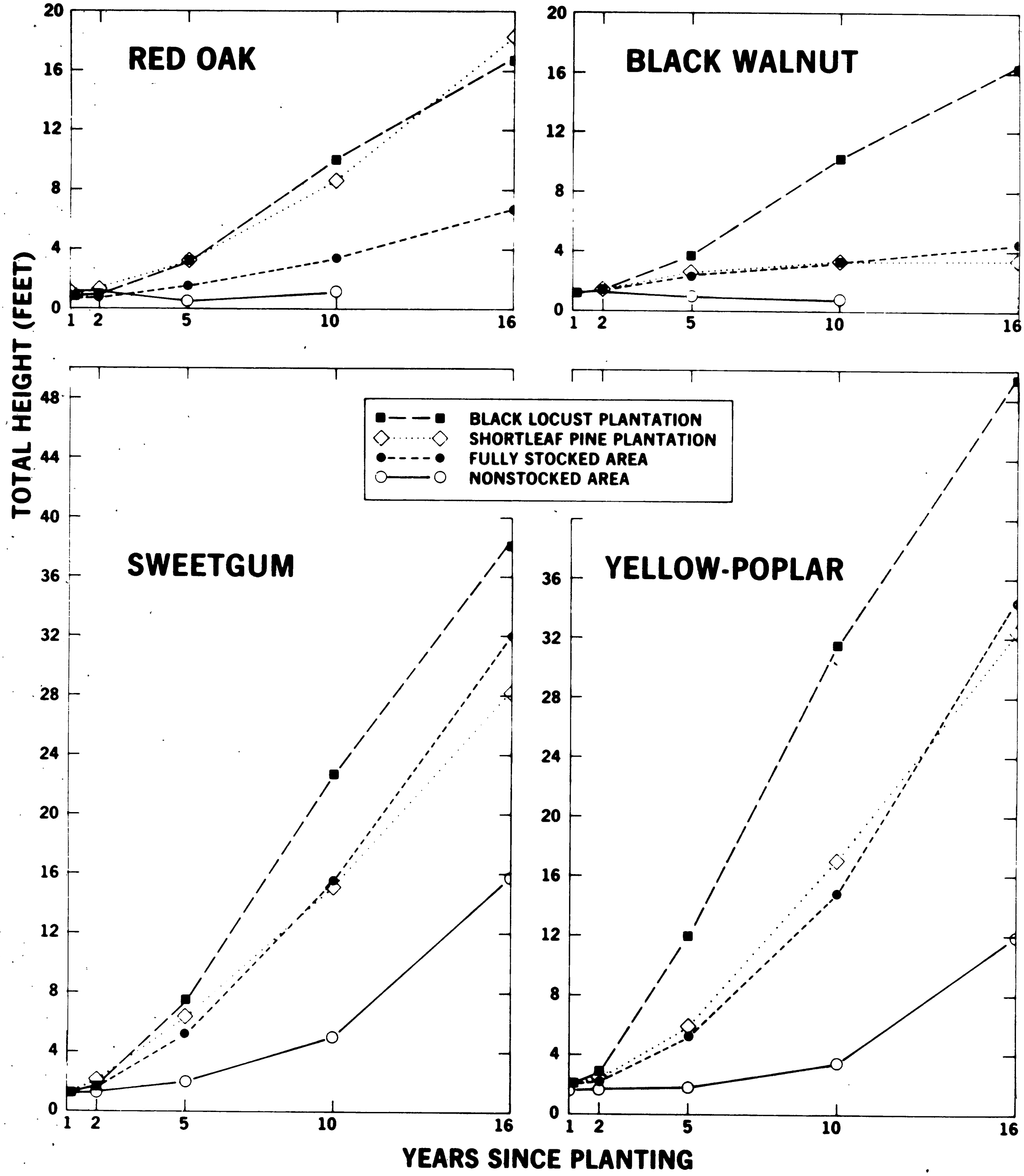

Figure 3.--*Total height growth for four hardwood species planted in four areas.*

For all species planted on the nonstocked area, 5-year foliar nitrogen levels were usually lower than for trees planted on the other three areas. However, on the non-stocked area, 10-and 16-year foliar nitrogen increased for most species. This increase

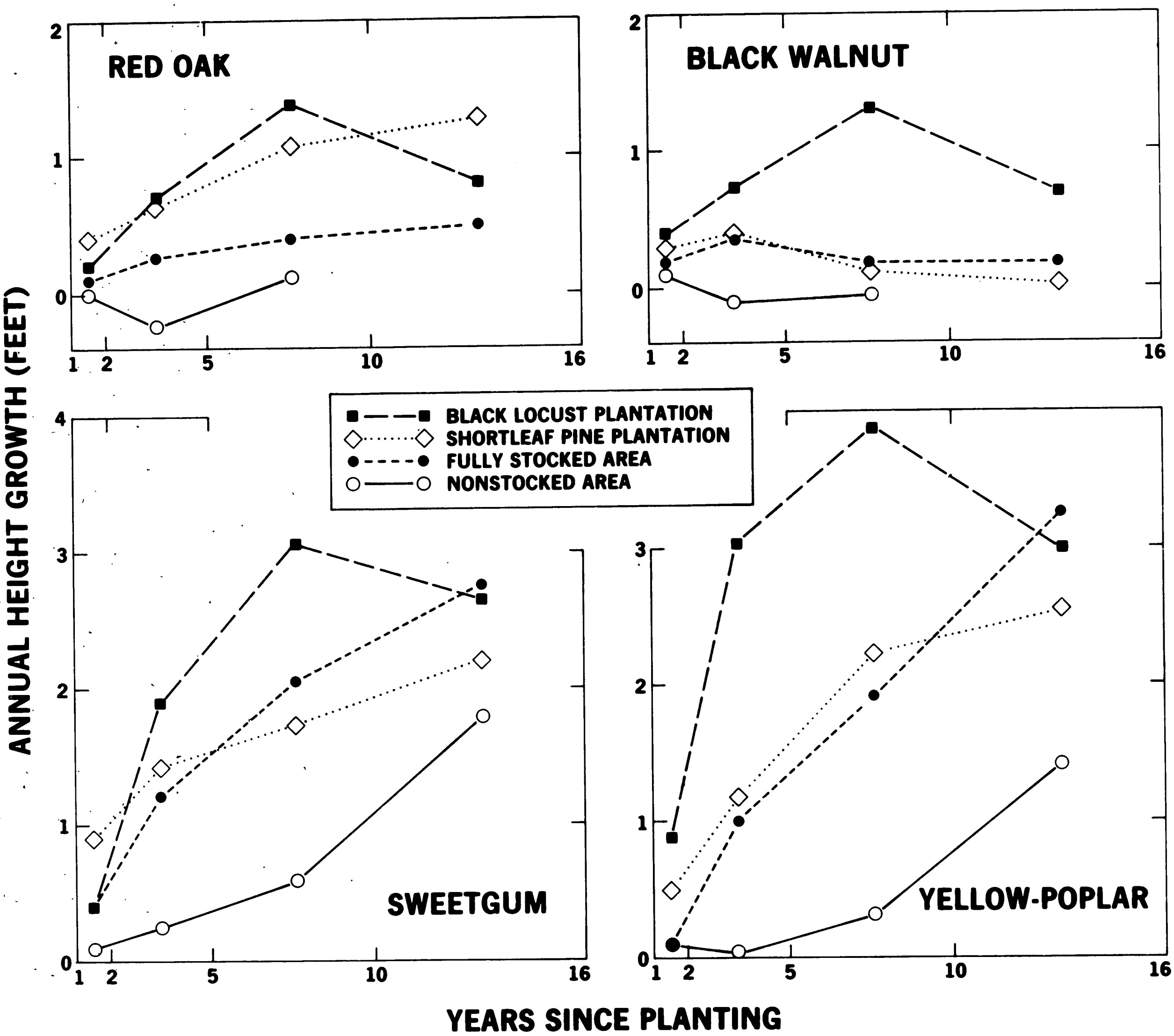

Figure 4.--*Annual height growth for four hardwood species planted in four areas.*

in foliar nitrogen on the nonstocked area corresponds to the increased growth in this area after 10 years for sweetgum and yellow-poplar. For all species planted on the locust area, 5-and 10-year foliar nitrogen was exceptionally high. However, foliar nitrogen decreased somewhat at 16 years for all species on the locust area which corresponds to the somewhat slower annual height growth after 10 years for all species planted on the locust area.

Annual height growth for black walnut, sweetgum, and yellow-poplar was usually related to foliar nitrogen at 5, 10, and 16 years (fig. 6). This relation was stronger at 5 and 10 years. The weaker relation at 16 years was due to less foliar nitrogen and slower growth for trees on the locust area, and to more foliar nitrogen and more rapid growth for trees on the nonstocked area.

Foliar phosphorus and potassium levels were similar at 5 and 10 years for all species on all areas, thus little relation existed between height growth and foliar content of these elements.

Soil Characteristics

Soil descriptions and analyses made in 1962 show that texture is similar for all

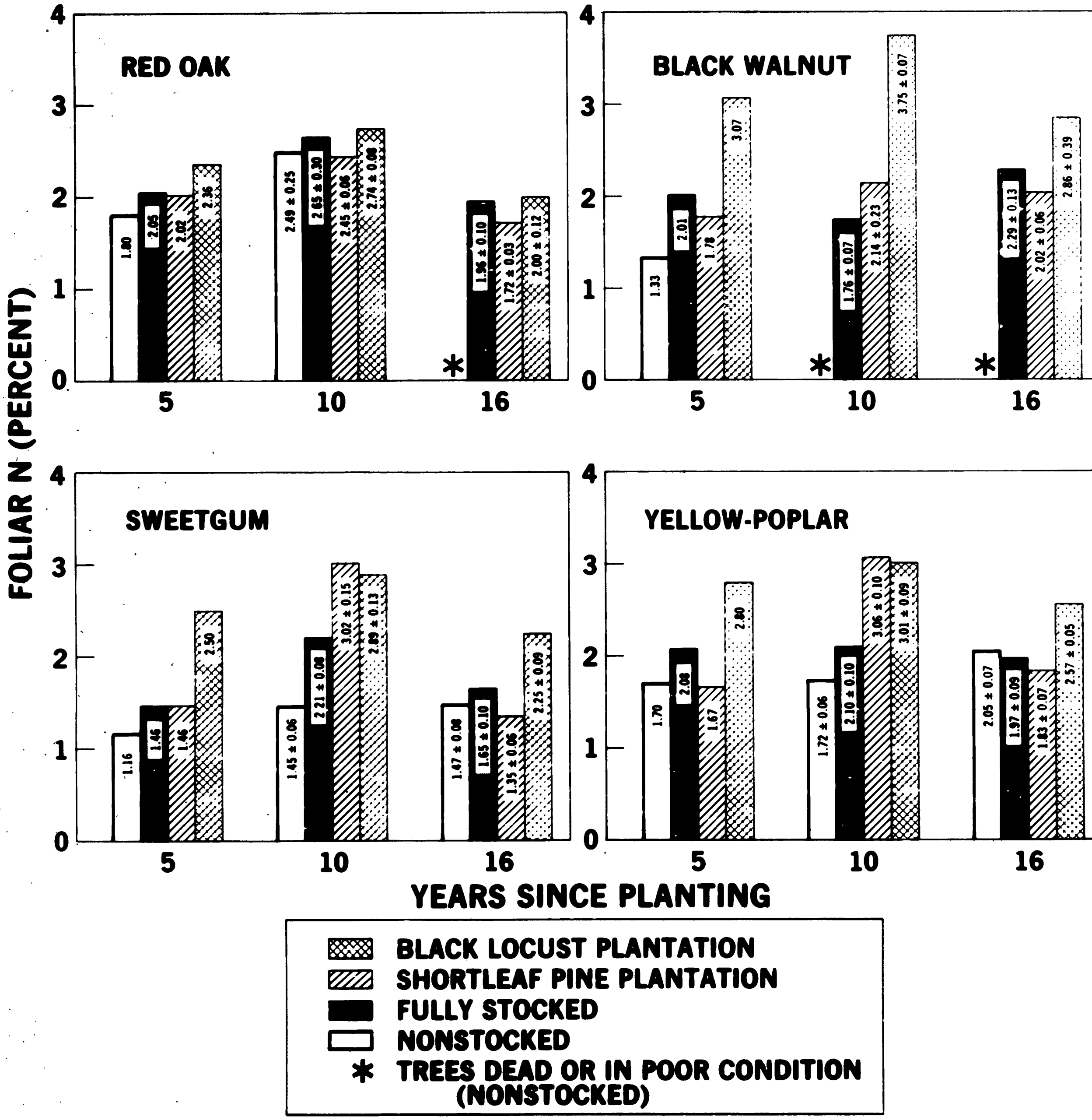

Figure 5.--*Foliar nitrogen levels for four hardwoods at 5, 10, and 16 years since planting. (Standard errors of the mean were not calculated at 5 years because foliar samples were composited into a single sample for each of the four vegetal cover areas.)*

study areas: silt content of the surface soil ranges from 59 to 63 percent, and clay content ranges from 26 to 29 percent (table 2). Surface soil depths (A1 and Ap horizons) also are similar (4 to 6 inches), except for the locust area where most of the original surface soil had eroded away. Depth to fragipan is about 20 inches for the Tilsit soil of the nonstocked and fully stocked areas; fragipan depth is about 33 inches for the Zanesville soil of the pine area, and about 22 inches for the eroded Zanesville soil of the locust area. "Available" phosphorus was uniformly low (about 2 p/m), and "available" potassium ranged from 29 to 89 p/m.

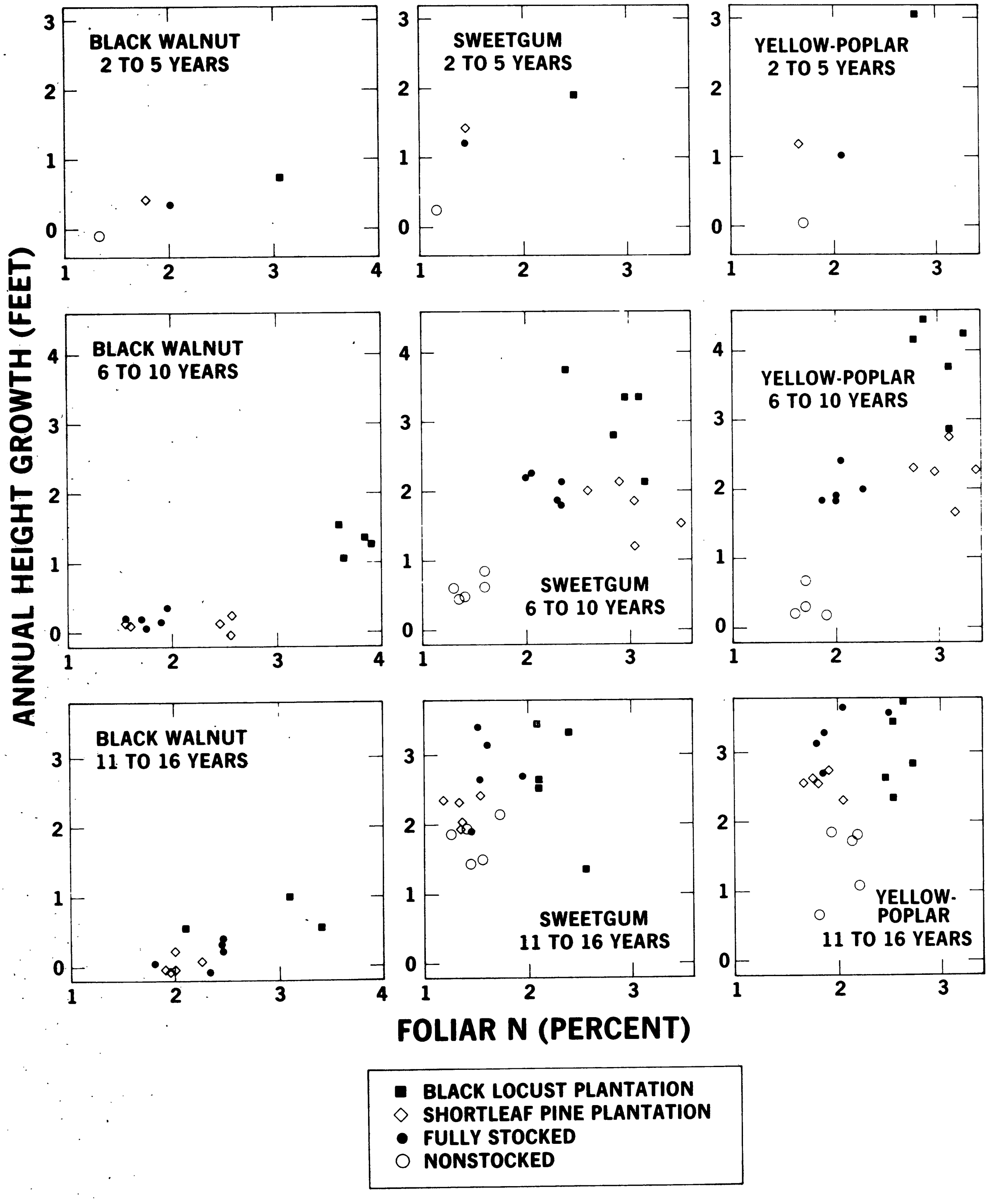

Figure 6.--*Relation of annual height growth for black walnut, sweetgum, and yellow-poplar to foliar nitrogen levels at 5, 10, and 16 years since planting.*

Measurements in 1962 showed that surface soil noncapillary pore volume, bulk density, and organic content differed greatly among the various study areas (fig. 7). The surface soil of the natural hardwood forest probably represents the original undisturbed surface soil conditions before clearing and farming. This surface soil has the highest organic content, lowest bulk density, and a high content of large, noncapillary pores. In contrast, the surface soil of the nonstocked area had little organic matter, and soils were dense and low in noncapillary pores; the locust area also had poor surface soil physical conditions because most of the original surface soil had been lost to erosion. Surface soils of the fully stocked and pine areas have surface soil physical conditions almost as good as those of the hardwood forest area. Thus, it appears that the presence of fully stocked stands of volunteer trees and shrubs, or planted pine, on agricultural land abandoned for about 23 years has changed surface soil physical conditions to approach the conditions of the hardwood forest area.

The surface soil layer in the locust area had the lowest noncapillary porosity, highest bulk density, and lowest organic content. These physical soil conditions are only a little better than those of the subsoil, probably because the surface soil layer of the locust area is mostly subsoil exposed by erosion before locust planting. The locust was planted in 1937 and clearcut for our studies in 1960, thus presence of black locust for 23 years apparently did not result in pronounced physical changes in what probably was mostly subsoil at the time the locust was planted.

Of course, subsoils are less porous and have less organic content than surface soils. Even so, subsoil physical conditions differed among the different vegetation conditions. The subsoil of the forest area, in contrast to the nonstocked area, had the most noncapillary pores, was less dense, and had the most organic content; these physical soil conditions were also fairly good in the fully stocked and pine areas. These somewhat better subsoil conditions for the hardwood forest, pine, and

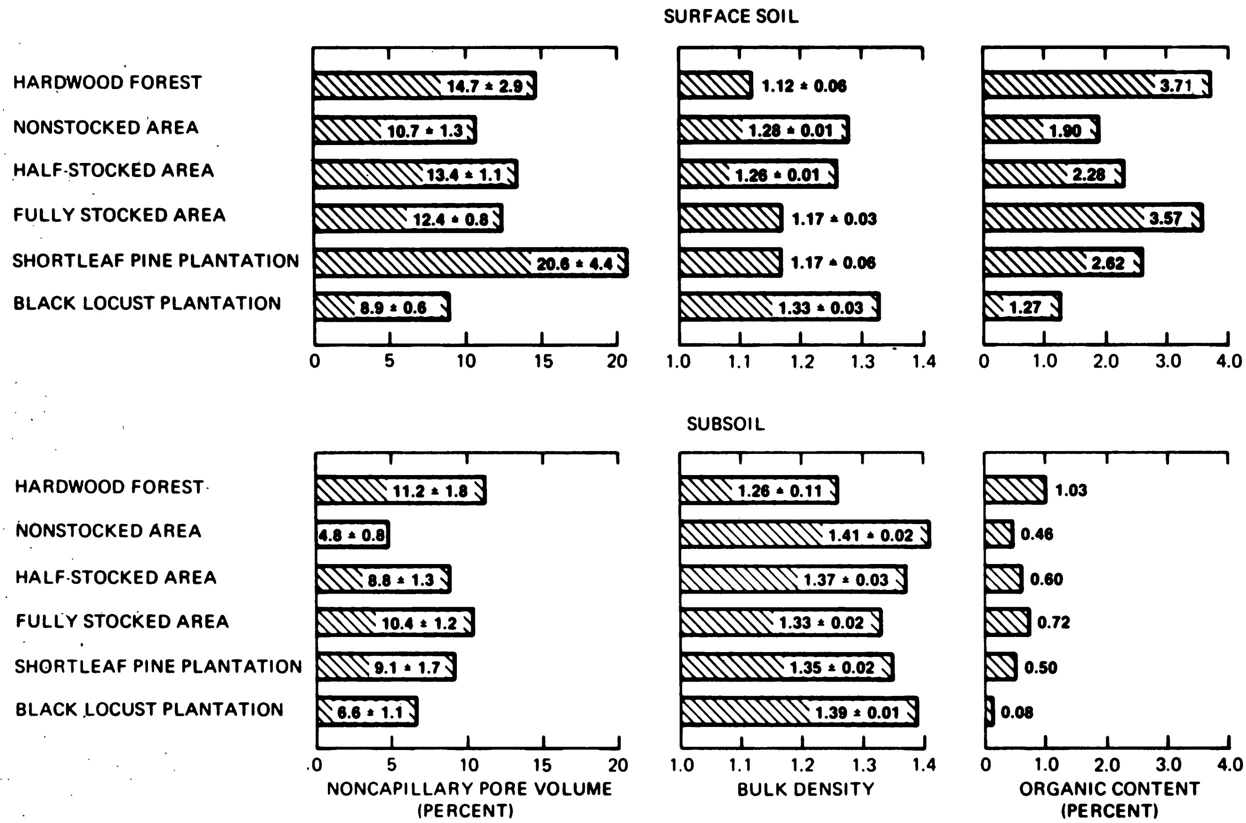

Figure 7.--*Noncapillary pore volume, bulk density, and organic matter content for the surface soil (1 to 4 inches) and subsoil (9 to 12 inches) of the six study areas.*

fully stocked areas probably are due to the long term presence of large, deep-rooted trees that produce subsoils having more root channels, more organic incorporation, and, as a consequence, more porous subsoils. Rolfe and Boggess (1973) observed similar subsoil differences for loess-derived soils in southern Illinois when they compared subsoils of grassy abandoned fields with subsoils of pine plantations.

Noncapillary pore volume, organic content, and bulk density are interrelated (fig. 8). Increased organic content is associated with decreased densities and with an increase in noncapillary pore volume. Naturally, more porous soils also have lower bulk densities.

Pot Culture Studies

Growth of yellow-poplar seedlings in undisturbed soil cores from the various study areas paralleled the growth of field planted seedlings (Clark 1964) (figs. 3 and 9). Yellow-poplar seedlings, as well as field-planted trees, had consistently poor growth in soil cores from the nonstocked area. Growth was better in cores from the fully stocked area and better yet in cores from the pine and hardwood forest areas. Exceptionally rapid growth was evident for yellow-poplar seedlings, as well as field-planted trees, in soil cores from the locust area.

Yellow-poplar seedlings in the soil cores, and in the field, usually grew better the greater the noncapillary porosity and organic content, and the less the bulk density (fig. 10). An exception was seedlings grown in soil from the black locust area where rapid growth occurred despite adverse soil physical conditions. The locust area probably has abundant soil nitrogen, as indicated by the large content of foliar nitrogen (fig. 3), and this large nitrogen supply might have more than offset the effects of poor physical soil conditions. Nitrogen relations in the locust area were so unlike those in the other areas that direct growth comparisons would be misleading. So, values for the locust areas were not included in the calculations illustrating how growth is correlated with noncapillary pore volume, bulk density, and organic content (fig. 10).

Yellow-poplar seedlings did not respond to phosphorus fertilizer when grown

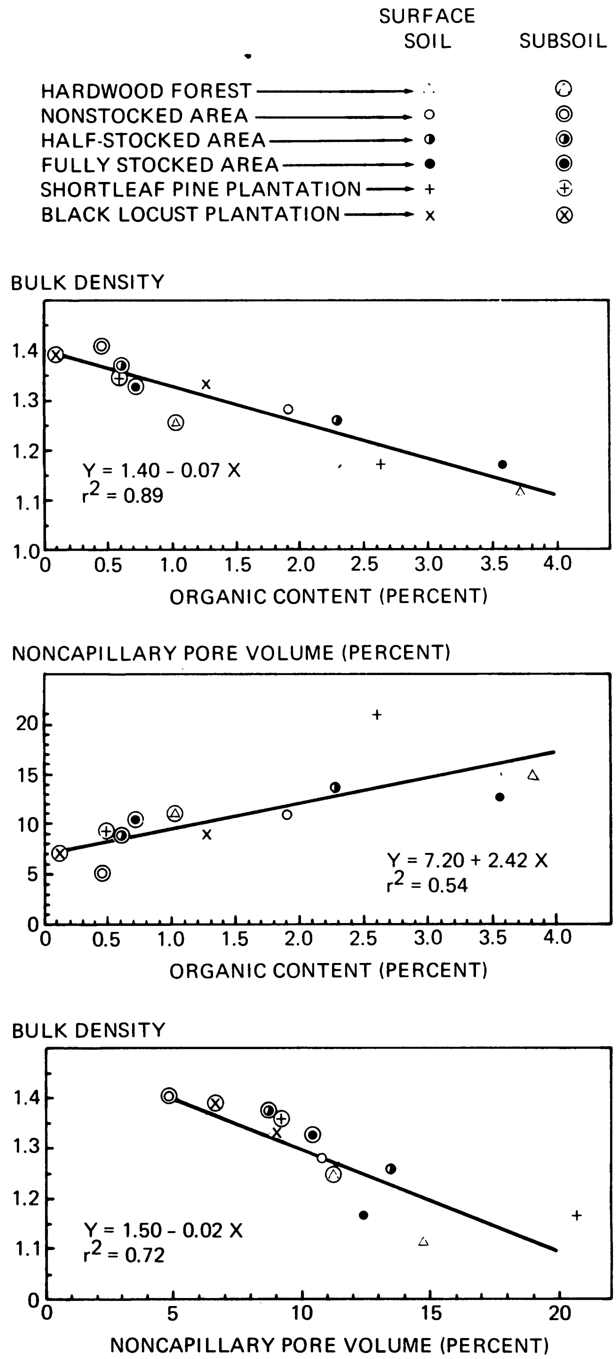

Figure 8.--*Relation of noncapillary pore volume, bulk density, and organic matter content.*

in undisturbed and unsterilized soil cores. After 15 weeks the fresh weight of seedlings fertilized with 0, 66, and 132 lbs/acre elemental phosphorus averaged 6.20 grams. In contrast, seedlings did respond significantly (0.05 and 0.01 level) to phosphorus

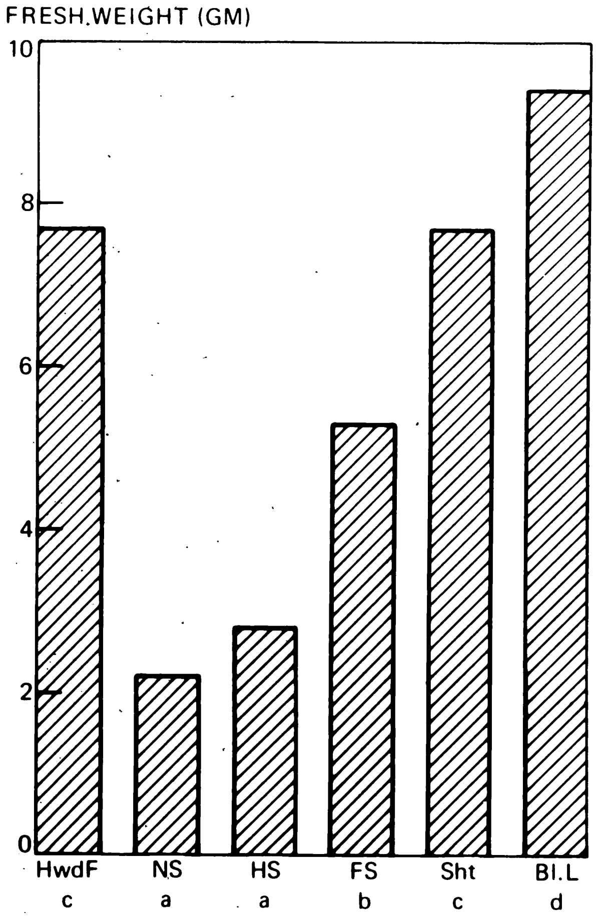

Figure 9.--*Fresh weight of yellow-poplar seedlings grown 12 weeks in undisturbed surface soil (0 to 6 inches) cores collected from six vegetal cover areas. (Areas having the same letter are not significantly different (0.01 level). HwdF = hardwood forest, NS = nonstocked area, HS = half-stocked area, FS = fully stocked area, Sht = shortleaf pine plantation, and Bl.L = black locust plantation.*

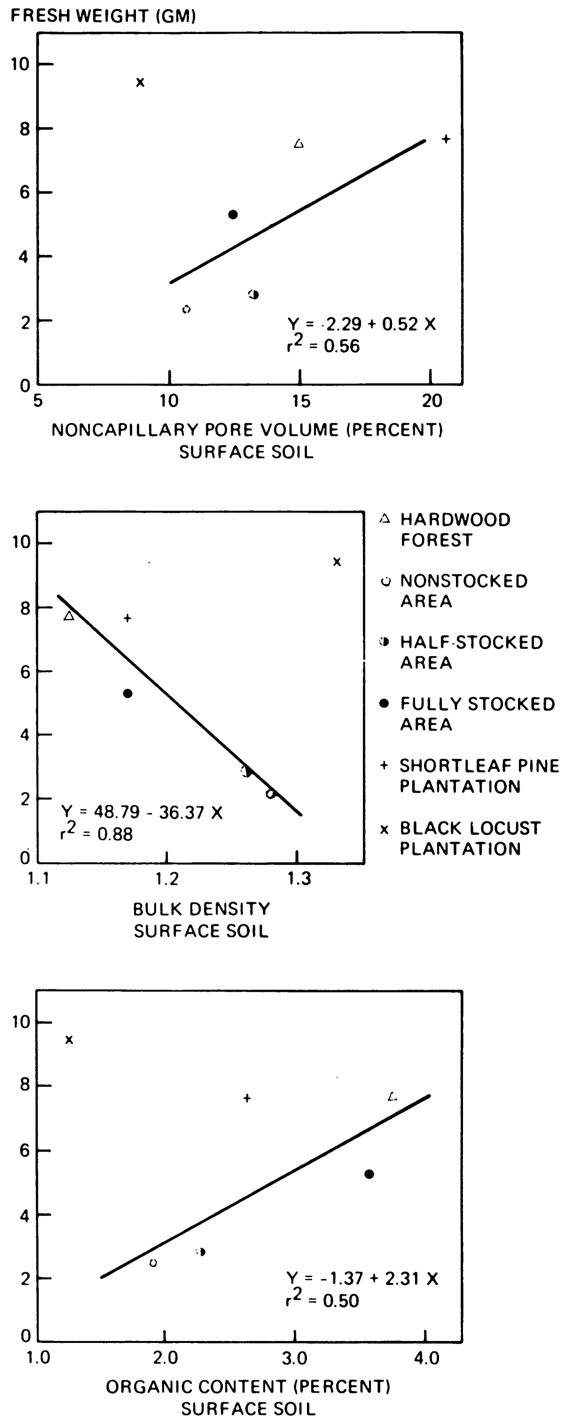

Figure 10.--*Weight of yellow-poplar seedlings grown in undisturbed surface soil (0 to 6 inches) cores collected from six vegetal cover areas was related to surface soil structure. (Correlations shown do not include seedlings grown in soil cores from the black locust area.)*

fertilizer when grown in undisturbed cores that had been sterilized with methyl bromide. After 15 weeks the fresh weight of seedlings fertilized with 0, 66, and 132 pounds of phosphorus averaged 1.33, 3.72, and 4.01 grams, respectively.

DISCUSSION AND CONCLUSIONS

This study is based only on a single plot in each of four vegetal cover areas. Thus, our results should be considered as a case history observation of tree growth on an abandoned field having contrasting vegetal cover conditions. Even though our study lacks statistical replication, we still consider the results meaningful because (a) we have observed great differences in growth on the four vegetal areas, (b) we have lengthy observations--16 years, and (c) we have found tree growth to be closely related to several important physical, chemical, and biological soil factors. Because of these many relations, we conclude that the striking growth differences we have observed are due to a complex of several interrelated physical, chemical, and biological factors rather than a single limiting factor. We hope our observations and hypotheses will provide some meaningful basis for future studies that explore in more detail the complex growth relations of hardwood trees on abandoned agricultural fields.

Physical Soil Relations

Some of the differences in soil physical conditions we observed in 1962 could have existed at the time the field was abandoned in the mid-1930's. Soils frequently change, even within small areas, but we do not believe normal soil variation is responsible for most of the pronounced differences in soil physical conditions among our four study areas. Obviously, soil conditions in the eroded locust plantation areas were initially much different from those in the other three areas. However, soil conditions for the nonstocked, fully stocked, and pine areas probably were similar at the time the field was abandoned. The three areas are adjacent, they have the same topographic position, and their surface soil depths and profile textures are almost identical (table 1). So, we attribute most of the present physical soil differences to the influence of different kinds of vegetation present for at least 23 years since land abandonment.

Our observations on differences in porosity, bulk density, and organic content agree closely with other studies showing pronounced soil changes resulting from old-field succession, or from planting trees on agricultural land (Auten 1933, 1941, 1945; Billings 1938; Coile 1940; Byrnes and Kardos 1963; Challinor 1968). Similar soil physical changes due to vegetal differences also have been reported for an abandoned field in southern Illinois having loess-derived soils (Rolfe and Boggess 1973, Fisher *et al.* 1975).

The soil physical differences we have observed are closely associated with the large growth differences for trees planted on our four areas. Better tree growth with better soil physical conditions also has been observed elsewhere (Youngberg 1959, Foil and Ralston 1967, Minore *et al.* 1969, Hatchell 1970). Agricultural crops also grow better with more favorable physical soil conditions. This is because soils that are porous and loose are better aerated, have more favorable temperature relations, root respiration is improved, mechanical resistance to root extension is lessened, and roots are better able to absorb soil moisture and nutrients (Lutz 1952, Russell 1952, Barley and Greacen 1967, Danielson 1972, Taylor *et al.* 1972). These relations between physical soil conditions and root physiology probably are partially responsible for the close associations we have observed between tree growth and noncapillary pore space, bulk density, and organic content (fig. 10).

Nitrogen Relations

Nitrogen-fixing nodules occur on black locust roots. Locust litter also returns large amounts of nitrogen to the soil, thus soils under locust stands contain abundant nitrogen (Ike and Stone 1958). Soil nitrogen contributed by black locust has long been known to stimulate growth of associated trees on both abandoned fields and strip-mined land (McIntyre and Jeffries 1932, Chapman 1935, Chapman and Lane 1951, Finn 1953). Likewise, hardwoods planted on our locust plot contain large amounts of foliar nitrogen and the sweetgum and yellow-poplar are growing remarkably fast. Apparently much of the nitrogen contributed by the locust remains 16 years after the locust was cut, and this nitrogen still is stimulating rapid tree growth.

Finn (1953) found that yellow-poplar, sweetgum, black walnut, and red oak interplanted with locust grew rapidly and had large amounts of foliar nitrogen. His results closely parallel the rapid growth and large amounts of foliar nitrogen we observed for these same species planted on our locust plot. We as well as Finn found that these hardwood species planted on abandoned fields without locust grew slowly and contained only small amounts of foliar nitrogen.

Early growth was outstanding on the eroded soil of the locust area even though the dense soil was low in organic matter and noncapillary pores. The abundant supply of nitrogen in the locust area perhaps compensated for poor physical soil conditions and thus stimulated early tree growth. But the large supply of nitrogen inherited from the previous locust stand may be diminishing with time, thus resulting in somewhat slower later growth. Measurements at 16 years of trees planted on the locust plot indicate that the initial high foliar nitrogen levels and initial rapid annual height growth may indeed be diminishing 10 years after planting.

At age 10 sweetgum and yellow-poplar planted on the fully stocked and pine areas also had more foliar nitrogen and were growing faster than trees on the nonstocked area. Finn (1953) likewise observed that hardwoods underplanted in a decadent shortleaf pine plantation in southern Illinois had more foliar nitrogen and better growth than hardwoods planted in a nearby abandoned field. One possible explanation for the better growth we observed is that the surface soils of the fully stocked and pine areas had more organic matter, and hence more soil nitrogen, than the surface soil of the nonstocked area. Another possible explanation is that soil organisms in the pine or hardwood root zones may mineralize or otherwise extract some fraction of soil nitrogen resistant to organisms in the root zone of the grasses in the nonstocked area. This was suggested by a study in New York (Fisher and Stone 1969, Stone and Fisher 1969) where total amounts of soil nitrogen and phosphorus were similar in abandoned fields, conifer plantations, and in the border zones. However, they found that more available nitrogen occurred in the conifer soils, presumably because of better mineralization of soil organic matter.

Endomycorrhizae Relations

Before concluding that soil physical conditions and nitrogen were exclusively responsible for our observed growth differences, we also considered the possible influence of other nutrients and soil mycorrhizae. Pot culture studies were designed to observe the role of these additional factors as well as complement the field studies.

Soil samples from all study areas contained little readily available phosphorus (table 2). This prompted a study of the response of pot-grown black locust and tomato (*Lycopersicon esculentum* Mill.) seedlings to nitrogen, phosphorus, and potassium fertilizers. Locust and tomato seedlings grown in disturbed soil samples collected from the hardwood forest, nonstocked, pine, and locust areas responded strongly to phosphorus fertilization (Hannah and Kohnke 1964).

Further studies were then made using yellow-poplar seedlings grown in undisturbed soil cores collected from the hardwood forest area. As already described we found no response to phosphorus fertilization for yellow-poplar seedlings grown in undisturbed soil cores, even though black locust and tomato grown in disturbed soil had responded to phosphorus (Hannah and Kohnke 1964). In contrast, yellow-poplar did respond strongly to phosphorus when growing in undisturbed cores that had been sterilized. Seedling roots were not examined in this study. However, other studies (Clark 1961, 1964), suggest that yellow-poplar roots growing in the unsterilized cores were infected with endomycorrhizae and thus able to absorb sufficient phosphorus despite low levels of "readily available" soil phosphorus. In contrast, yellow-poplar seedlings growing in the sterilized cores probably lacked endomycorrhizae; this apparently resulted in insufficient phosphorus absorption, and thus seedlings in sterilized soil responded to phosphorus fertilization. This view is supported by studies showing that vesicular-arbuscular endomycorrhizae present on roots of yellow-poplar and sweetgum result in increased uptake of soil phosphorus (Gray and Gerdemann 1967).

The rapidly growing yellow-poplar seedlings growing in undisturbed cores from the hardwood forest, the pine area, and the locust area had well developed endomycorrhizae (Clark 1964).[3] But the slow-growing seedlings in undisturbed soil cores from the nonstocked area were "weakly" infected and the hyphae within seedling root cells appeared to be disintegrating. Clark (1964) also found that yellow-poplar seedlings grown in screened surface soils from the hardwood forest were much smaller than seedlings grown in undisturbed cores of the

[3]*Examinations for endomycorrhizae were made by Edward Hackskaylo, Plant Physiologist, USDA Forest Service, Beltsville, Maryland.*

same soil. He concluded that screened soils as well as soils from the nonstocked area were more dense, less porous, and less aerated. These poorer physical soil conditions thus may have affected endomycorrhizal activity and hence the ability of yellow-poplar seedlings to absorb sufficient soil nutrients and moisture. Later reports on endomycorrhizae also emphasize that good soil physical conditions result in better oxygen supply and greater root metabolic activity, thus favoring endomycorrhizal development and better phosphorus uptake for trees growing on infertile soils (Gerdemann 1968, Gray 1969, Harley 1969). Apparently the physiological activity of endomycorrhizae on our hardwood seedling roots was closely related to soil physical conditions and to the ability of the hardwood seedlings to absorb sufficient amounts of soil nitrogen and phosphorus. Additional studies of these interrelations may more precisely define their role in hardwood tree growth.

Allelopathic Relations

Several herbaceous species occurring in the early stages of old-field succession contain allelopathic compounds that inhibit nitrogen-fixing and nitrifying bacteria (Rice 1964, 1974). The broomsedge that dominated our nonstocked area has allelopathic compounds in both roots and shoots that inhibit root nodulation and the growth of legumes. Such allelopathic compounds are an important competitive mechanism favoring plants having low nitrogen requirements. For example, in eastern Oklahoma allelopathic compounds produced by broomsedge inhibit the growth of several competing plant species, thus enabling broomsedge to dominate old fields for many years (Rice 1972). Also allelopathic compounds in broomsedge reduced the growth of loblolly pine (*Pinus taeda* L.) seedlings.[4]

The broomsedge dominating the nonstocked area may have produced allelopathic compounds that inhibited the growth of our planted hardwoods. Sassafras, present in our fully stocked area, has recently been shown to produce allelopathic compounds that influence old-field succession in Tennessee (Gant and Clebsch 1975). Broomsedge in our nonstocked area may have produced allelopathic compounds that inhibited nitrogen-fixing soil organisms and also endomycorrhizal development. As a result, the supply of nitrogen, phosphorus, and other nutrients may have been limited, thus resulting in poor early growth of our planted hardwoods. But the initially slow-growing hardwoods planted in the nonstocked area gradually attained dominance after 10 years, thus reducing the density of the broomsedge. So the influence of allelopathic compounds produced by broomsedge may be diminishing, judging from the increased foliar nitrogen and increased annual height growth observed at 16 years for sweetgum and yellow-poplar planted on the nonstocked area.

[4] *Priester, D. S., and M. T. Pennington. 1976. Inhibitory effects of broomsedge* (Andropogon virginicus *L.*) *on the growth of young loblolly pine* (Pinus taeda *L.*) *seedlings. USDA For. Serv., Southeast. For. Exp. Stn., Asheville, North Carolina: (Unpublished Ms.)*

APPLICATION OF RESULTS

The reasons are complex for the striking differences in growth that we observed for hardwoods planted on an abandoned field having contrasting vegetal cover conditions. Apparently several important physical, chemical, and biological soil factors are involved and more detailed studies are needed before we can fully understand their complex interrelations.

Even though the basic reasons for our growth differences are complex, hardwoods obviously grow much faster when planted on old fields where soils have been modified physically, chemically, and biologically by the presence of well stocked stands of trees. The time required for these soil modifications is uncertain, but our studies on a single abandoned field indicate that soil conditions are improved for planted hardwoods during 23 years under forest cover.

Shortly after abandonment many upland old fields are invaded by aggressive, brushy vegetation. Many such areas are good sites for trees but in the past were usually not planted because land clearing and brush control were difficult and expensive. Our studies suggest that on good upland sites this tree and shrub cover will improve growing conditions for more desirable hardwoods. Therefore, such areas can be considered good hardwood planting sites now that better mechanical and chemical methods are available for brush control and for converting brushy areas to desirable hardwood plantations.

Our studies also indicate that pine stands improve growing conditions for planted hardwoods. So, on good upland sites, conversion to commercially valuable hardwoods might be desirable following an initial rotation of pine. This was done in southern Illinois where yellow-poplar made excellent growth when planted in a clearcut portion of a shortleaf pine plantation (Young *et al.* 1969). Furthermore, an initial rotation of nitrogen-fixing tree species, such as black locust, alder (*Alnus* spp.), or autumn-olive (*Elaeagnus umbellata* Thunb.)[5] may improve soil conditions for certain eroded and less favorable sites, thus better growth and survival might be achieved when these areas are converted to valued hardwoods.

---

[5]*Unpublished 7-year results show significant increases in height and diameter growth for black walnut when interplanted with autumn-olive (D. T. Funk, North Cent. For. Exp. Stn., Carbondale, Illinois).*

LITERATURE CITED

Auten, J. T. 1933. Porosity and water absorption of forest soils. J. Agric. Res. 46(11):997-1014.

Auten, J. T. 1941. Forest soil properties associated with continuous oak, old-field pine, and abandoned field cover in Vinton County, Ohio. USDA For. Serv. Tech. Note 34, 8 p. Cent. States For. Exp. Stn., Columbus, Ohio.

Auten, J. T. 1945. Relative influence of sassafras, black locust, and pines upon old-field soils. J. For. 43:441-446.

Barley, K. P., and E. L. Greacen. 1967. Mechanical resistance as a soil factor influencing the growth of roots and underground shoots. Adv. Agron. 19:1-43.

Billings, W. D. 1938. The structure and development of old field shortleaf pine stands and certain associated physical properites of the soil. Ecol. Monogr. 8:437-499.

Bouyoucos, G. J. 1951. A recalibration of the hydrometer method for making mechanical analysis of soils. Agron. J. 43: 434-437.

Byrnes, W. R., and L. T. Kardos. 1963. Hydrologic characteristics of three soils supporting natural hardwoods, planted red pine, and old field plant communities. Soil Sci. Soc. Am. Proc. 27: 468-473.

Challinor, D. 1968. Alteration of surface soil characteristics by four tree species. Ecology 49:286-290.

Chapman, A. G. 1935. The effects of black locust on associated species with special reference to forest trees. Ecol. Monogr. 5:37-60.

Chapman, A. G., and R. D. Lane. 1951. Effects of some cover types on interplanted forest tree species. USDA For. Serv. Tech. Pap. 125, 15 p. Cent. States For. Exp. Stn., Columbus, Ohio.

Clark, F. B. 1961. Pot culture--an aid to site evaluation. Indiana Acad. Sci. Proc. 70:234-237.

Clark, F. B. 1964. Micro-organisms and soil structure affect yellow-poplar growth. USDA For. Serv. Res. Pap. CS-9, 12 p. Cent. States For. Exp. Stn., Columbus, Ohio.

Coile, T. S. 1940. Soil changes associated with loblolly pine succession on abandoned agricultural land of the Piedmont Plateau. Duke Univ. Sch. For. Bull. 5, 85 p.

Danielson, R. E. 1972. Nutrient supply and uptake in relation to soil physical conditions. In Optimizing the soil physical environment toward greater crop yields. p. 193-221. D. Hillel, ed. Academic Press, New York.

Finn, R. F. 1953. Foliar nitrogen and growth of certain mixed and pure forest plantings. J. For. 51:31-33.

Fisher, R. F., G. L. Rolfe, and R. P. Eastburn. 1975. Productivity and organic matter distribution in a pine plantation and an adjacent old field. Illinois Agric. Exp. Stn. For. Res. Rep. 75-1, 3 p.

Fisher, R. F., and E. L. Stone. 1969. Increased availability of nitrogen and phosphorus in the root zone of conifers. Soil Sci. Soc. Am. Proc. 33:955-961.

Foil, R. R., and C. W. Ralson. 1967. The establishment and growth of loblolly pine seedlings on compacted soils. Soil Sci. Soc. Am. Proc. 31:565-568.

Gant, R. E., and E. E. C. Clebsch. 1975. The allelopathic influences of *Sassafras albidum* in old-field succession in Tennessee. Ecology 56:604-615.

Gerdemann, J. W. 1968. Vesicular-arbuscular mycorrhiza and plant growth. Ann. Rev. Phytopathol. 6:397-418.

Gray, L. E. 1969. Uptake of phosphorus 32 by vesicular-arbuscular mycorrhizae. Plant & Soil 30:415-422.

Gray, L. E., and J. W. Gerdemann. 1967. Influence of vesicular-arbuscular mycorrhizae on the uptake of phosphorus 32 by *Liriodendron tulipifera* and *Liquidambar styraciflua*. Nature 213:106-107.

Hannah, P. R., and H. Kohnke. 1964. Pot studies indicate need of fertilization in reforestation of abandoned cropland in southern Indiana. Indiana Acad. Sci. Proc. 72:252-256.

Harley, J. L. 1969. Mycorrhiza and nutrient uptake in forest trees. In Second Long Ashton Symp. Proc., p. 163-179. Univ. Bristol.

Hatchell, G. E. 1970. Soil compaction and loosening treatments affect loblolly pine growth in pots. USDA For. Serv. Res. Pap. SE-72, 9 p. Southeast For. Exp. Stn., Asheville, North Carolina.

Ike, A. F., Jr., and E. L. Stone. 1958. Soil nitrogen accumulation under black locust. Soil Sci. Soc. Am. Proc. 22: 346-349.

Leamer, R. W., and B. Shaw. 1941. A simple apparatus for measuring noncapillary porosity on an extensive scale. J. Am. Soc. Agron. 30:1003-1008.

Limstrom, G. A. 1963. Forest planting practice in the Central States. U.S. Dep. Agric., Agric. Handb. 247, 69 p.

Lutz, J. F. 1952. Mechanical impedance and plant growth. In Soil physical conditions and plant growth. p. 43-71. B. T. Shaw, ed. Agron. II, Academic Press, New York.

McIntyre, A. C., and C. D. Jeffries. 1932. The effect of black locust on soil nitrogen and growth of catalpa. J. For. 30:22-28.

Minore, D., C. E. Smith, and R. F. Woollard. 1969. Effects of high soil density on seedling growth of seven northwestern tree species. USDA For. Serv. Res. Note PNW-112, 6 p. Pac. Northwest For. & Range Exp. Stn., Portland, Oregon.

Rice, E. L. 1964. Inhibition of nitrogen-fixing and nitrifying bacteria by seed plants. Ecology 45:824-837.

Rice, E. L. 1972. Allelopathic effects of *Andropogon virginicus* and its persistence in old fields. Am. J. Bot. 59: 752-755.

Rice, E. L. 1974. Allelopathy. 353 p. Academic Press, New York.

Rolfe, G. L., and W. R. Boggess. 1973. Soil conditions under old field and forest cover in southern Illinois. Soil Sci. Soc. Am. Proc. 37:314-318.

Russell, M. B. 1952. Soil aeration and plant growth. In Soil physical conditions and plant growth. p. 253-301. B. T. Shaw, ed. Agron. II, Academic Press, New York.

Stone, E. L., and R. F. Fisher. 1969. An effect of conifers on available soil nitrogen. Plant & Soil 30:134-138.

Taylor, H. M., M. G. Huck, and B. Klepper. 1972. Root development in relation to soil physical conditions. In Optimizing the soil physical environment toward greater crop yields. p. 57-77. D. Hillel, ed. Academic Press, New York.

Walkley, A. 1947. A critical examination of a rapid method for determining organic carbon in soils-effect of variations in digestion conditions and of inorganic soil constituents. Soil Sci. 63:251-264.

Young, R. A., A. R. Gilmore, and W. R. Boggess. 1969. Underplanting yellow-poplar in a shortleaf pine plantation in southern Illinois. Uiv. Illinois Agric. Exp. Stn. For. Note 125, 4 p.

Youngberg, C. T. 1959. The influence of soil conditions following tractor logging, on the growth of planted Douglas-fir seedlings. Soil Sci. Soc. Am. Proc. 23:76-78.

☆ U.S. Government Printing Office: 1976—766—077/13 Region No. 6

THE AUTHORS

Willard H. Carmean is Project Leader and Principal Soil Scientist for the Station's research on site requirements of northern hardwood species. Dr. Carmean did his undergraduate work in forestry at Pennsylvania State University and earned his M.F. in silviculture and Ph. D. in forest soils from Duke University. His Forest Service career began at the Pacific Northwest Forest & Range Experiment Station where he studied the soil-site requirements of Douglas-fir. At the Central States and North Central Forest Experiment Stations he did similar work on upland oaks, black walnut, and (currently) northern hardwoods. In 1974 he spent 4 months in Malaysia as an F.A.O. consultant on soil-site problems of caribbean pine.

F. Bryan Clark has been with the Forest Service for 27 years as a research forester and administrator in three Experiment Stations. His research has been primarily in stripmine reclamation and in hardwood silvics and silviculture. Much of his work was concentrated on black walnut. He received forestry degrees from Purdue University and the University of Missouri and a Ph.D. in Botany from Southern Illinois University. He is presently Director of the Northeastern Forest Experiment Station.

Robert D. Williams is a Principal Silviculturist with the North Central Forest Experiment Station's research project "Culture, Genetics and Protection of Fine Hardwoods", and is located at Bedford, Ind. He received a B.S. degree in Forestry from Purdue University. Before joining the Forest Service in 1956 he served for 7 years as district forester and service forester for the State of Missouri. He is currently responsible for research involving plantation establishment and culture, and hardwood nursery practices.

Peter R. Hannah studied forestry at the University of Vermont and earned degrees at the University of Maine (1959), and Yale University (1960). He was employed for 1 year with the Bureau of Land Management in Coos Bay, Oregon, and then joined the Central States Forest Experiment Station at Bedford, Indiana, in 1961. In 1964, he left the Central States Station to attend the University of Michigan where he earned his Ph.D. in forest soils in 1967. Since then he has been teaching and doing research on culture of high-valued northern hardwoods, in the Department of Forestry, School of Natural Resources, University of Vermont, where he holds the rank of Associate Professor.

Carmean, Willard H., F. Bryan Clark, Robert D. Williams, and Peter R. Hannah.
1976. Hardwoods planted in old fields favored by prior tree cover. USDA For. Serv. Res. Pap. NC-134, 16 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

Hardwoods were planted in a long-abandoned field. Growth was poor in a grassy area, better in areas formerly having natural trees or planted pine, and outstanding in an area formerly having planted black locust. Improved growth was associated with better soil structure and more foliar nitrogen.

OXFORD: 181.32:182.21. KEY WORDS: old-field succession; physical, chemical, and biological soil conditions; foliar nitrogen.

Carmean, Willard H., F. Bryan Clark, Robert D. Williams, and Peter R. Hannah.
1976. Hardwoods planted in old fields favored by prior tree cover. USDA For. Serv. Res. Pap. NC-134, 16 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

Hardwoods were planted in a long-abandoned field. Growth was poor in a grassy area, better in areas formerly having natural trees or planted pine, and outstanding in an area formerly having planted black locust. Improved growth was associated with better soil structure and more foliar nitrogen.

OXFORD: 181.32:182.21. KEY WORDS: old-field succession; physical, chemical, and biological soil conditions; foliar nitrogen.