

**INFLUENCE OF SOIL AND TOPOGRAPHY
ON WILLOW OAK SITES**

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Southern foresters and forest landowners are often faced with the necessity of estimating the productive capacity of their hardwood sites. The Southern Forest Experiment Station is developing techniques for using soil and topographic characteristics to predict site index (average height of dominants at age 50 years) for many commercially important southern hardwood species.

The results of field and laboratory work have provided a guide for the evaluation of site quality of willow oak (Quercus phellos L.) on areas supporting very young or abused stands or where this species is completely absent.

Willow oak was studied first in the series because its natural occurrence on a variety of sites permitted tests of a wide range of soil variables. Some of the many closely interrelated and reliable measures of site quality were water-holding capacity, soil reaction, proportion of particles by size class, and topographic relationships.

Willow oak is shown to be related in its growth habit to stand density, topographic position, and percent of clay in Mississippi Delta soils. In other river and stream bottoms of the South, the amount of available potassium, instead of percent of clay, is used to predict site index. These criteria were chosen because of their ready application by practicing foresters.

^{1/} Stationed at the Delta Research Center, Stoneville, Mississippi. The Delta Research Center is maintained in cooperation with the Mississippi Agricultural Experiment Station and the Southern Hardwood Forest Research Group.

The cooperation of industry members of the Southern Hardwood Forest Research Group and the Southern Hardwood Forestry Group in the field location of willow oak stands for this study is gratefully acknowledged. Credit is due also to the Soil Testing Service of Mississippi State College for chemical characterizations of all soil profiles.

Work is in progress on the site requirements of other commercially important hardwoods. Ultimately, comparative indices will be available on any one site for many indigenous species.

METHODOLOGY

Eighty-three willow oak stands were sampled--50 on sites in the Mississippi River Delta and 33 in the bottomlands of other streams in the Southern Coastal Plain (fig. 1). Delta locations range from northern Tennessee to south of Natchez, Mississippi, on both sides of the river, but east of Crowley's Ridge in Arkansas. Non-Delta installations extend from the Neches River of eastern Texas to the Tombigbee and Alabama River system and include five in the ancient Mississippi floodplain west of Crowley's Ridge.

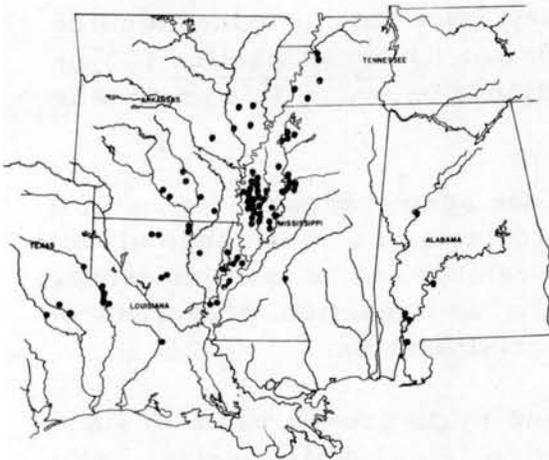


Figure 1. --Willow oak site plots are distributed in many alluvial bottoms of the South as well as in the Delta or Lower Mississippi River Valley.

for samples. Basal areas of the sampled stands ranged from 70 to 140 square feet per acre.)

Sample trees, of which there averaged more than two per plot, were bored for total age at 4-1/2 feet above the ground and accurately measured for total height with an Abney level. Many were felled to facilitate ring count, to check height measurements, and to provide height-growth data.

There were a total of 183 willow oak sample trees. Criteria for the choice of a sample was:

1. --It must be a dominant or upper co-dominant of a 30- to 60-year-old group.

2. --It must be of single-stemmed, non-bushy habit and, upon increment core examination, not show evidence of past suppression (fig. 2).

3. --It must be surrounded by neighbors so that the adjacent area is reasonably well-stocked. (Trees that had not had competition and thus could not be classified as group-dominants were not chosen

Analysis of over 100 willow oak seedlings on varying sites provided data for adjusting age at breast height to total age. Two years were added to the breast-height ring count.

Complete stand and log-quality data were recorded on a 1/5-acre plot surrounding the sample tree. Perennial ground cover was listed in order of occurrence for its possible indicator plant value.

Topographic features were recorded and soil samples taken. A composite soil sample was collected for each depth, as described below, from two or more 5-inch auger holes on the plot. During very dry weather, the heavy alluvial clays were so hard as to preclude augering. Soil pits were then required. The prevalent sites with azonal profiles were sampled at the arbitrary depths of 0-6 inches, 12-18 inches, 24-30 inches, and 36-42 inches. A 1-inch auger was used to sample further to about 7 feet. In the few instances where a horizon or layer-like differentiation occurred, soil was taken from each layer.

Physical properties and some chemical properties of the soils were analyzed in the laboratory of the Delta Experiment Station, Stoneville, Mississippi. The Soil Testing Service of Mississippi State College ran a chemical characterization of all profiles--the same characterization as that made for farm operators. Percentage of organic matter and pounds of P_2O_5 equivalent per acre were determined colorimetrically with a flame photometer. Pounds of exchangeable potassium per acre was determined turbidimetrically by precipitating the potassium as sodium potassium cobalti-nitrite.

Soil pH was measured with a glass electrode both in the field and in the Stoneville laboratory. Since no important differences were

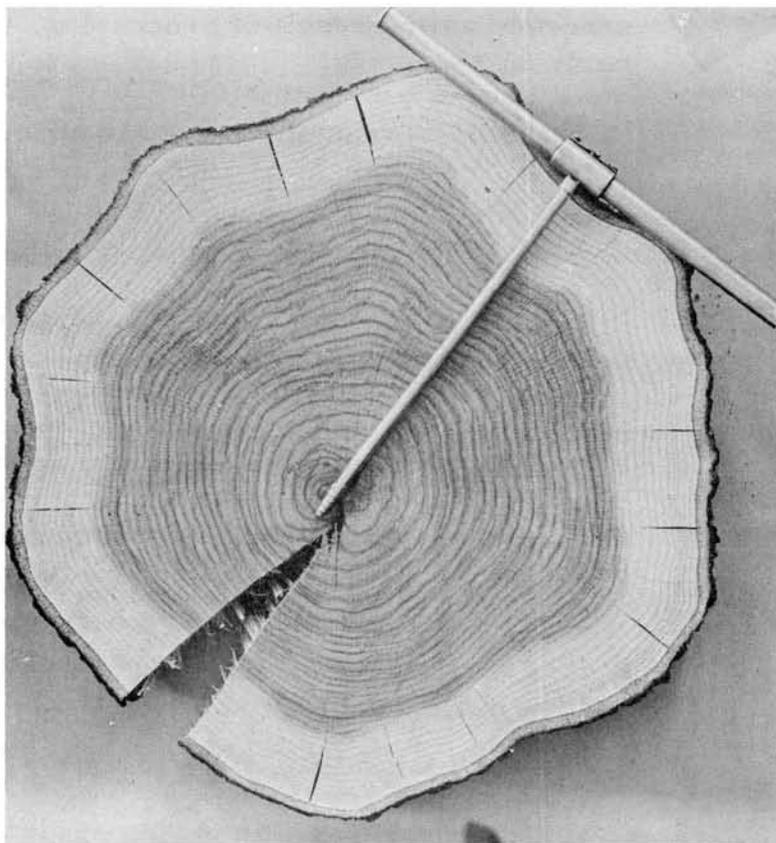


Figure 2.--Radial growth pattern typical of willow oaks sampled in this study. Any evidence of past suppression disqualified a tree. Note the effect of the last four years' drouth.

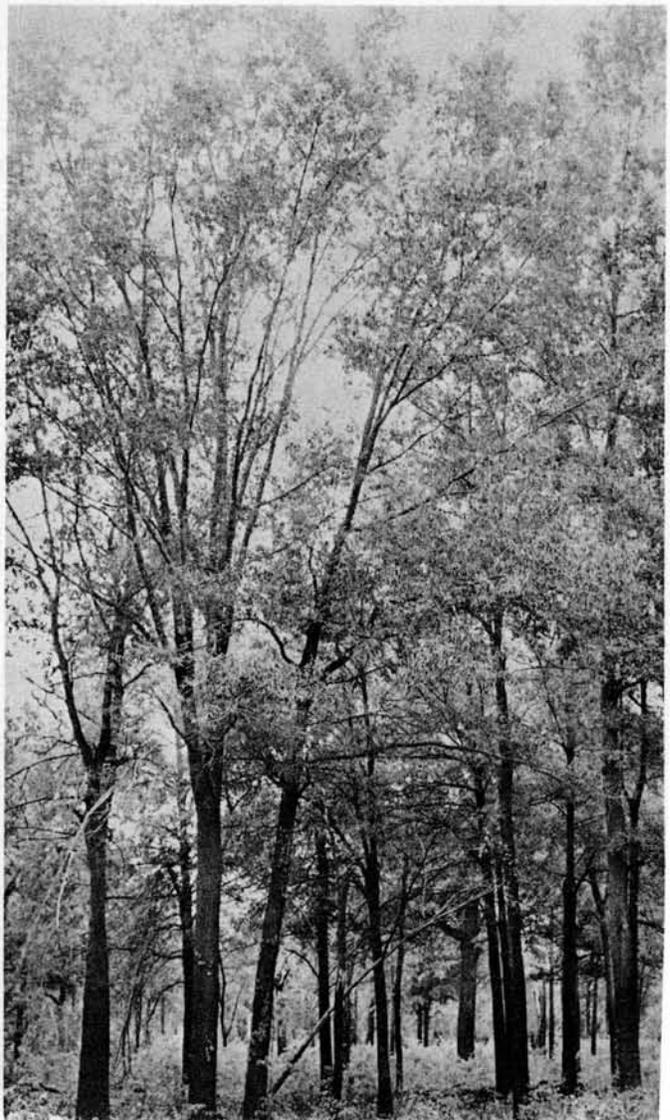
observed as the result of processing, the field technique was discontinued early in the study.

All soil samples were air-dried and ground or rolled to pass a 2 mm. sieve. Mechanical analysis by the hydrometer method, moisture and xylene equivalent through centrifugation, and p. p. m. of ferric and total iron determined colorimetrically completed the important laboratory tests.

RESULTS

Data from both Delta and non-Delta sample plots indicate the importance of bottomland topography to tree growth. Small variations in relief on Mississippi River alluvium make for large differences in site index. It is apparent that poor surface drainage has a deleterious effect on willow oak sites. Extended periods of inundation can cause harmful concentration of soil elements as well as reduced activity of essential soil fauna.

Figure 3. -- Willow oak on good (left) and poor sites. Merchantable height and log quality decrease as total height at a given age diminishes.



Many of the soils variables tested showed high correlation with the total height of dominant willow oak adjusted to 50 years of age. In the search for methods which could be readily adapted to use by practicing foresters, some complex soils determinations were dropped despite their significant relationship to site index. The same applies to variables in the less accessible subsoils (table 5, p. 11).

The relative amounts of clay and available potassium were chosen from many reliable indicators for two reasons: first, they are part of the regular schedule of soil testing provided by various State agencies and, second, both may be determined with inexpensive soil testing equipment and simple procedures. Clay percentage is used as the key soil variable in the Delta and available potassium in other southern river bottoms.

A multiple regression of the form $y = b_0 + b_1 + b_2 x_2 \dots b_n x_n$ was fitted where y equals total height adjusted for age and the x 's are transformed soil and topographic variables and their cross-products. Height at age 50 was calculated through a separate linear regression which yielded an adjustment of 0.85 feet per year. Variation in observed ages was limited by choosing sample trees between 30 and 60 years. Most age adjustments were for less than 10 years.

There are two final regression equations corresponding to the two parts of figure 4. Important multipliers and coefficients for each are presented in table 4, p. 10. Other regressions tested are to be found in table 6, p. 12.

Surface grade of butt logs on all sample trees regardless of size was recorded according to the Interim Sawlog Grades for Southern Hardwood^{2/}. Plots were classified according to the average grade of the sample trees. Results of this analysis indicate a significant gain in log quality with site index increase. With butt logs classified as 1, 2, 3, and 4

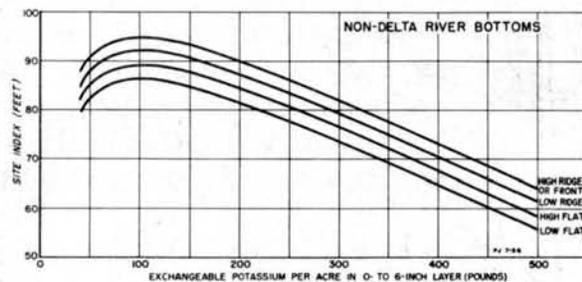
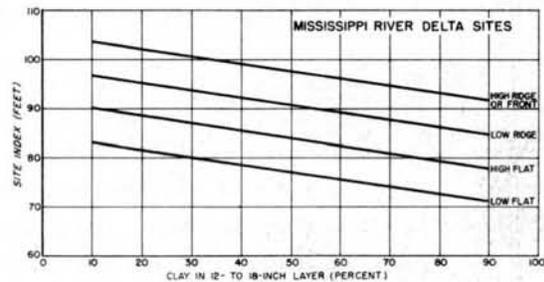


Figure 4. --Average height of dominant willow oak, age 50, at a basal area of 110 square feet per acre.

^{2/} Lockard, C. R., and Carpenter, R. D. Interim sawlog grades for southern hardwoods. U. S. Forest Serv. Southern Forest Expt. Sta., 9 pp., illus. Rev. 1948.

Table 1. --Unadjusted sample plot averages according to site quality

Site quality	Field measurements			
	Grade	D. b. h.	Basal area per acre	Total age
		Inches	Square feet	Years
60-74	3.8	13	90	51
75-84	3.2	15	104	46
85-94	2.4	17	114	44
95+	1.8	21	136	45

in order of descending quality, the averages for each site-quality group are recorded in table 1.

The occurrence of possible indicator plants is so varied as to require much more detailed study. So far, the data refute the commonly advanced hypothesis that palmetto is associated with poor sites. Palmetto was found on the best as well as the poorest sites.

APPLICATION

Topographic position must be established on alluvial sites of unknown quality. Since many foresters managing southern hardwoods are already familiar with the classifications outlined by Putnam^{3/}, these further refined definitions will be applied:

High ridge or front: The highest land found in alluvial bottoms. These are the banks of former channels or presently active main watercourses where seasonal overflows have deposited most of the larger sediment particles. Built up as natural levees, they are rarely inundated. Surface drainage is superior to that in other topographic classes.

Low ridge: Topographic map inspection is often necessary to distinguish these from high ridges. Only a few feet lower than the preceding class, they are more numerous, formed as banks of older, smaller, sluggish, or less permanent watercourses. Also included here are sites located on the gently sloping sides of the high ridges.

High and low flats: "Flat" well describes the broad area between ridges. It is easily recognized by its poor surface drainage and wide dimensions. It tends to have a higher proportion of clay in its make-up. The difference between

^{3/} Putnam, J. A. Management of bottomland hardwoods. U.S. Forest Serv. Southern Forest Expt. Sta. Occas. Paper 116, 60 pp. 1951.

high and low flats is one of degree. A logical line of demarcation may be drawn by the rate of drainage after flooding or heavy rainfall. Those flats which are free of water within a few days after the river or stream is again between banks, or after the heaviest seasonal rains, may be classified as high. Low flats often retain a cover of water for several weeks longer or even into the early growing season.

Since elevation changes are difficult to discern, there is no substitute for previous experience in the bottomland to be classified. Aerial photos, water lines on trees, and the condition of the forest floor will provide an adequate basis for ascertaining the topographic class of an alluvial site. Figure 5 illustrates site differentiation during a period of receding high water.

It is then necessary to obtain a representative sample of the soil from the unknown site. Two to four auger holes per acre will provide an adequate sample in homogenous alluvial soils. Elevation change dictates additional soil samples with a separate site estimate. Occasionally, dry, heavy clays cannot be augered. Then pits must be dug to the appropriate depth. The several samples from a particular site are mixed together or composited. Most soil testing services require about a quart of the composited soil.

Those interested in willow oak site index in the Delta will sample for clay 12 to 18 inches below the soil surface. The percent clay in the sample may be determined in the office by use of hydrometers and cylinders which may be purchased from scientific supply houses. All determinations should be duplicated to avoid errors in procedure.

When topographic class and percent clay have been determined, the site index is read from table 2. None of the soils samples in the study contained more than 45 percent sand and table 2 should not be applied where a higher proportion of sand is encountered.

Site indices for bottomlands outside the Delta are estimated by use of the topographic

Table 2. --Average total height of dominant willow oak at age 50 years on Delta sites

Clay in 12-18 inch layer (percent)	Topographic class			
	High ridge or front	Low ridge	High flat	Low flat
	- - - - Feet - - - -			
10	104	97	90	83
20	102	95	89	82
30	101	94	87	80
40	99	92	86	79
50	98	91	84	77
60	96	89	82	76
70	95	88	81	74
80	93	86	79	72
90	92	84	78	71



Figure 5. -- Typical river-bottom topography. Ridges drain after heavy rains while the adjacent flats are flooded. Low flats remain under water several times as long as do high flats.

classification and a measure of the pounds of available potassium per acre. Samples for this determination may be taken in the top 6 inches of the soil. A composite sample from several points is again required. Before the samples are taken, the litter should be scraped off down to mineral soil. The potassium determination may be made by the appropriate State agricultural agency or with a field kit like those made for testing agricultural land. Site index for non-Delta locations may be read from table 3.

Table 3. --Average total height of dominant willow oak at age 50 years on non-Delta sites

Available K per acre in 0-6 inch layer (lbs.)	Topographic class			
	High ridge or front	Low ridge	High flat	Low flat
	- - - - - Feet - - - - -			
50	91	88	85	83
100	95	92	89	87
150	93	90	88	85
200	90	87	84	82
250	86	83	80	78
300	82	79	76	74
350	78	75	72	69
400	73	70	68	65
450	69	66	63	60
500	64	61	59	56

Because of its independence from other stand variables, total height of dominants has usually been considered as the best measure of site quality. However, because willow oak tends to be bushy when open grown, its height will vary with the density of the stand. Therefore, tables 2 and 3 have been adjusted to a standard basal area of 110 square feet per acre of all trees 6 inches d. b. h. and larger.

Prior agricultural improvements may have unbalanced the chemical relationships in abandoned fields. The growth potential of newly established forest stands on such sites may best be measured by test plantings.

APPENDIX

Table 4. -- Willow oak site-index regression data

Mississippi River Delta sites: relationship of basal area, topography, and clay to site index	Non-Delta sites: relationship of basal area, topography, and available potassium to site index
Y = b ₀ + b ₁ x ₁ + b ₂ x ₂ + b ₃ x ₃	Y = b ₀ + b ₁ x ₁ + b ₂ x ₂ + b ₄ x ₄ + b ₅ x ₅
Mean squared residual = 42.61	Mean squared residual = 57.72
Degrees of freedom = 46	Degrees of freedom = 28
Mean Y = mean height of willow oak at age 50 years = 87.88	Multiple correlation coefficient = 0.772 ^{1/}
Mean x ₁ = mean basal area of surrounding 1/5-acre plot (trees with d. b. h. larger than 5.95 inches) = 22.40 sq. ft.	Mean Y = 88.67
Mean x ₂ = mean topographic value (high ridge = 10, low ridge = 20, high flat = 30, low flat = 40) = 22.20	Mean x ₁ = mean basal area of surrounding 1/5-acre plot (trees with d. b. h. larger than 5.95 inches) = 23.76 sq. ft.
Mean x ₃ = mean percent clay in zone 12-18 inches below ground surface = 61.14 percent	Mean x ₂ = mean topographic value (high ridge = 10, low ridge = 20, high flat = 30, low flat = 40) = 26.67
Coefficient of multiple correlation = 0.787 ^{1/}	Mean x ₄ = mean pounds per acre of exchangeable potassium in layer 0-6 inches below soil surface = 151.58 lbs.
b ₀ ^{2/} = + 99.600086 b ₂ = -0.689285	Mean x ₅ = 10,000 mean reciprocal of x ₄ = 82.33
b ₁ = + 0.577163 b ₃ = -0.152869	b ₀ ^{2/} = + 95.076060 b ₄ = -0.094119
c ₀₀ ^{3/} = + .73177698 c ₂₁ = - .00006581	b ₁ = + 0.944032 b ₅ = -0.086539
c ₁₀ = - .01543866 c ₃₁ = + .00006236	b ₂ = - 0.279228
c ₂₀ = - .00300104 c ₂₂ = + .00027246	c ₀₀ ^{3/} = + 1.18709082 c ₁₁ = + .00092319 c ₂₃ = - .00001523
c ₃₀ = - .00489578 c ₃₂ = - .00002573	c ₁₀ = - .01866917 c ₂₁ = - .00000873 c ₂₄ = - .00001517
c ₁₁ = + .00058425 c ₃₃ = + .00006657	c ₂₀ = - .00474104 c ₃₁ = + .00000136 c ₃₃ = + .00001229
	c ₃₀ = - .00247576 c ₄₁ = - .00003931 c ₃₄ = + .00001198
	c ₄₀ = - .00256957 c ₂₂ = + .00031895 c ₄₄ = + .00002541

^{1/} Significant to the 1-percent level.

^{2/} Subscripts are those of variable subscripts in term.

^{3/} Subscripts denote order of single or joint term appearance in regression, not variable subscripts in term.

Table 5. -- Variables used in final regression analysis ^{1/}

Variables employed in Table 4

- Y = average total heights of dominants adjusted to 50 years of age (in feet)
- x₁ = basal area of all trees 6 inches and larger on 1/5-acre plot (in square feet)
- x₂ = topographic class coded as follows:
 10--high ridge or front 20--low ridge
 30--high flat 40--low flat
- x₃ = percent clay in 12-18 inch depth
- x₄ = pounds per acre exchangeable potassium in 0-6 inch depth
- x₅ = $\frac{1}{x_4}$ (10,000)

Other independent variables tested

- x₆ = percent clay in 24-30 inch depth
- x₇ = percent clay in 36-42 inch depth
- x₈ = imbibitional water value in 12-18 inch depth
- x₉ = imbibitional water value in 24-30 inch depth
- x₁₀ = imbibitional water value in 36-42 inch depth
- x₁₁ = pounds per acre available equivalent P₂O₅ in 0-6 inch depth
- x₁₂ = pounds per acre available equivalent P₂O₅ in 24-30 inch depth
- x₁₃ = percent sand in 0-6 inch depth
- x₁₄ = percent sand in 24-30 inch depth
- x₁₅ = pH of 12-18 inch depth
- x₁₆ = pH of 36-42 inch depth
- x₁₇ = log of p. p. m. of ferric iron in 24-30 inch depth
- x₁₈ = log of p. p. m. of total iron in 24-30 inch depth
- x₁₉ = difference between elevation of plot and 1947 l. w. p. at outlet (each watershed handled separately)
- x₂₀ = distance to watershed outlet
- x₂₁ = number of trees 6 inches and larger on 1/5-acre plot
- x₂₂ = pounds per acre exchangeable potassium in 12-18 inch depth

^{1/} Adjusted site index was plotted over each independent variable prior to analysis. Inspection eliminated many obviously non-significant variables.

Table 6. -- Regressions that were inferior to the final form or not as suitable for practical application

$$Y = f (K, x_1, x_{19}, x_{10}, x_{10}^2)$$

$$Y = f (K, x_1, x_2, x_3, x_3^2, x_3^3, 1/x_3, x_2x_3)$$

$$Y = f (K, x_1, x_2, x_4, x_{22}, 1/x_4)$$

$$Y = f (K, x_{17}, x_{18}, x_{17} x_{18}, x_{10}, x_{22}, x_{16}^{-x_{15}})$$

$$Y = f (K, x_{20}, x_{19}, x_{20} x_{19}, x_{16}^{-x_{15}}, x_{10})$$

$$Y = f (K, x_1, x_2, x_8, x_{22})$$

$$Y = f (K, x_{19}, x_{16}^{-x_{15}}, x_{19} x_{16}^{-x_{15}})$$

$$Y = f (K, x_3, x_3^2, x_{16}^{-x_{15}}, x_{16})$$

$$Y = f (K, x_3, x_8, x_{16}^{-x_{15}}, x_{18}, x_7, x_{10})$$