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SITE-SPECIES RELATIONSHIPS FOR SOUTHERN HARDWOODS

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The high cost of land and forest management make selection of sites suitable for planting hardwoods particularly important. Hardwoods have exacting soil requirements, and productivity can change significantly with small changes in conditions. The purpose of this paper is to review some of the attempts to evaluate sites for southern hardwoods, with emphasis on an approach recently developed by Baker and Broadfoot (1977).

Many scientists have described the sites on which hardwoods grow well (e.g., Williamson 1913; Turner 1937; Putnam, Furnival, and McKnight 1960). Basically, they agree that hardwoods grow best on fertile, deep soils having adequate moisture and aeration during the growing season. Almost all the efforts to classify sites systematically according to potential productivity for southern hardwoods are by Walter M. Broadfoot or his associates (Beaufait 1956; Broadfoot and Krinard 1959; Broadfoot 1960; Broadfoot 1961; Broadfoot 1963; Broadfoot 1964a; Broadfoot 1964b; Broadfoot 1969; Broadfoot 1970; Broadfoot, Blackmon, and Baker 1972; Broadfoot 1976; Baker and Broadfoot 1977).

OBJECTIVE APPROACH

Broadfoot (1969) used independent soil-site variables and multiple regression analysis to predict site index for sweetgum, green ash, cottonwood, and cherrybark, water, willow, and Nuttall oaks. No strong relationships were found; R values ranged from .38 for green ash to .67 for cottonwood. When Broadfoot's equations were tested on new populations, the maximum differences between actual and predicted site index were great--from 18 to 38 feet, depending on the species.

Better correlations than those of Broadfoot (1969) were found by White and Carter (1970). They found cottonwood site index at age 6 to be positively related to soil potassium -- R = .97. But their research was confined to young stands in a limited geographic area; Broadfoot's work was conducted over a five-state region where widely varying soil conditions were encountered.

Broadfoot (1969) attributed the lack of precision of his equations to an inability to measure the true causes of productivity. He believed productivity to be determined by moisture and nutrient availability during the growing season, soil aeration, and physical conditions including root growing space. Apparently, the standard methods of assessing these factors did not adequately indicate how much nutrients, moisture, and air are available to the tree.

FREQUENCY-OF-OCCURRENCE APPROACH

As early as 1964, Broadfoot had developed a subjective, but useful, system of classifying sites based on the frequency with which hardwoods occur on various soils (Broadfoot 1964b). This approach presented more than 100 soil series by physiographic province and topographic position and the frequency with which different species occurred under each condition. The system also included general management recommendations for various site-species combinations.

Broadfoot (1976) updated the information using site index values from his 1969 publication. This later report presents the following information for 40 Midsouth soil series: (1) measured average site index, (2) estimated site index range, (3) information on frequency of occurrence of the various species,

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Table 1. *Species suitability and productivity on ADLER soils*

Species	Management and occurrence	Suitability	Site index: Estimated range	Site index: Measured average	Site index: Converted from sweetgum
Ash, green	A+	1	105- 85		84
Baldcypress	C	1-2	110- 90		
Birch, river		(2)	85- 65		
Boxelder	C				
Catalpa	C				
Cherry, black	C	2	95- 75		
Chinaberry	C				
Cottonwood, eastern	A	1	130-110		95
Elms, American and slippery	C+	1	95- 75		
Hackberry and sugarberry	B	1	100- 80		
Honeylocust	C	1	95- 75		
Locust, black	C				
Maple, red	C	2	90- 70		
Mulberry	C				
Oak, bur	C				
Oak, cherrybark	B	1-2	115- 95	100	98
Oak, Nuttall	B	1-2	115- 95	114	94
Oak, pin	C				
Oak, water	B	1-2	110- 90		92
Oak, willow	B	1-2	110- 90	94	96
Pecan	B	2	100- 80		
Persimmon, common	C	2	85- 65		
Red cedar, eastern	C				
Sassafras	C	2	95- 75		
Sweetgum	A+	1-2	110- 90	95	
Sycamore, American	A+	1	125-105	110	
Walnut, black	B	1	100- 80	88	
Willow, black	B	2	90- 70		
Yellow-poplar	B	1-2	115- 95	102	

A+ Favor in management; suitable for planting; occurs frequently.

B+ Favor in management; occurs frequently.

C+ Manage but do not favor; occurs frequently.

D+ Weed species on this soil; retain if useful for wildlife; occurs frequently.

A Favor in management; suitable for planting; occurs occasionally.

B Favor in management; occurs occasionally.

C Manage, but do not favor; occurs occasionally.

D Weed species on this soil; retain if useful for wildlife; occurs occasionally.

1 Best growth; among the top soil-species combinations for production.

1-2 Growth ranges from best to good.

2 Good productivity with proper management.

2-3 Growth ranges from good to fair.

3 Fair to poor growth.

3-4 Poor to unsuited.

4 Unsuited.

( ) Species is not known to occur naturally on this soil. Suitability rating is by opinion.

(4) general management recommendations, and (5) a suitability classification ranging from "unsuited" to "best" (table 1). In addition, soil physical and chemical data are included.

LATEST APPROACH

The above techniques have serious limitations. Broadfoot (1969) pointed out that the problems associated with selecting and quantifying soil variables over a wide geographic area and statistically correlating them with tree heights appear to be insurmountable. The frequency-of-occurrence techniques, particularly if soil series is included, can be quite useful. However, the system is restricted to the soils Broadfoot (1976) classified and requires the ability to identify soils by series name.

To date, the approach of Baker and Broadfoot (1977) is the most useful technique developed. The growth of hardwoods depends on four major soil factors (Broadfoot 1969; Broadfoot, Blackmon, and Baker 1972): (1) physical condition, (2) moisture availability during the growing season, (3) nutrient availability, and (4) aeration. The basis of the new approach is the assumption that each major factor is responsible for a certain portion of tree growth (table 2). In turn, the growth attributed to each major factor consists of contributions made by several soil-site conditions that together make up the major factor (table 2).

Site-quality ratings (SQR's) or site index ratings have been assigned to a range of soil-site conditions that are likely to occur for each major soil factor (table 2). Site index for any of eight species--cottonwood, sweetgum, sycamore, green ash, and Nuttall, water, willow, and cherrybark oaks--can be obtained by examining soil conditions in the field. These conditions are compared with the conditions listed for each soil-site property for a particular species to assign a numerical rating to each. The sum of these ratings is the site index.

Here is an example of how the method works. Assume that the site to be evaluated is a recently abandoned old field in a southern Coastal Plain stream bottom that had been under cultivation for 9 years and fertilized annually. The area is level and subject to flooding during winter. The soil is a sandy loam, has moderate profile development, has an 8-inch A horizon, and is granular in structure. The soil is deep, not compacted, and has no pans. It is brown and has no mottling. A water table occurs at 9 feet. The pH is 6.0 and there is less than 1 percent organic matter in the A horizon.

By using table 2 and assigning the values to match the characteristics of our hypothetical site and summing them as below, a site index value for sweetgum is obtained (93 ft. at 50 years).

(1) Physical condition	SQR	(2) Moisture availability	SQR	(3) Nutrient availability	SQR	(4) Aeration	SQR
		Water table	3	Geologic			
		Pans	6	source	2		
Soil depth		Position	5	Past use	4		
and pans	6	Structure	5	% organic			
Texture	4	Microsite	1	matter	-2	Structure	8
Compaction	6	Texture	0	Topsoil	5	Swampiness	8
Structure	6	Flooding	3	Soil age	2	Mottling	7
Past use	5	Past use	1	pH	1	Color	7
Total	27 ft.		24 ft.		12 ft.		30 ft.
(Total possible)	(30 ft.)		(36 ft.)		(24 ft.)		(30 ft.)
						SITE INDEX =	93 ft.

Table 2. — *Soil-site properties influencing the four major soil factors and thus sweetgum growth*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
	Factor 1. Physical condition		
Soil depth and presence of artificial or inherent pan	Deep soil (> 4 feet); without pan [6][1]	Medium depth (2-4 feet), or a soil with a plowpan [4]	Shallow soil (< 2 feet), or a soil with an inherent pan [-2]
Texture (in rooting zone)	Medium-textured; silty or loamy [4]	Coarse-textured; sandy [2]	Fine-textured; clayey [1]
Compaction (in surface foot)	No compaction; loose, porous, friable, bulk density < 1.4 g/cc [6]	Moderately compacted; firm, moderately tight, bulk density 1.4-1.7 g/cc [4]	Strongly compacted; tight, bulk density > 1.7 g/cc [-2]
Structure (in rooting zone)	Granular; blocky single-grained; massive (if sandy, loamy, or silty) [6]	Prismatic; platy [4]	Massive (if clayey) [0]
Past use and present cover	Undisturbed; near-virgin forest cover [8]	Moderate cultivation; cultivated < 20 years, or open with grass [5]	Intensive cultivation; cultivated > 20 years, or open and bare [2]
	Factor 2. Moisture availability during growing season		
Water table depth	2-6′ [6]	1-2′; 7-10′ [3]	< 1′ [unsuitable]; > 10′ [-3][2]
Artificial or inherent pans	No pans [6]	Plowpan [3]	Inherent pan [-3]
Topographic position	Floodplain or stream bottom [5]	Stream terraces or lower slopes [3]	Upland [-2]
Microsite	Concave; depression, pocket, trough [2]	Level; flat [1]	Convex; ridge, mound [-2]
Structure (in rooting zone)	Granular; blocky; massive (if silty, loamy, or clayey); stratified [5]	Prismatic; platy [3]	Massive (if sandy); single-grained [-1]
Texture (in rooting zone)	Silty or loamy, (or stratified) [5]	Clayey [2]	Sandy [0]
Flooding	Winter through spring [5]	Winter only [3]	None [0]; Continuous [Unsuitable]
Past use and present cover	Undisturbed; near-virgin, forest cover [2]	Moderate cultivation; cultivated < 10 years [1]	Intensive cultivation; cultivated > 10 years [0]

Continued

Table 2. — *Soil-site properties influencing the four major soil factors and thus sweetgum growth (continued)*

Soil-site property	Soil-site condition and relative quality		
	Best	Medium	Poor
Factor 3. Nutrient availability			
Geologic source	Mississippi River, Loess, Blackland [5]	Mixed Coastal Plain and other [4]	Coastal Plain [2]
Past use and present cover	Undisturbed; near-virgin, forest cover, cultivated < 5 years [5]	Moderate cultivation; cultivated 5-10 years, or open with grass [3][3]	Intensive cultivation; cultivated > 10 years, or open and bare [1][3]
Organic matter (A-horizon)	> 2% [4]	1-2% [2]	< 1% [-2]
Depth of topsoil (A-horizon)	> 6" or no profile development [5]	3-6" [2]	< 3" [-3]
Soil age	Young, no profile development (Entisols) [4]	Medium, moderate profile development (Inceptisols) [2]	Old, well-developed profile, leached (Alfisols) [0]
pH (in rooting zone)	5.5-7.5 [1]	4.5-5.5 or 7.6-8.5 [0]	< 4.5 or > 8.5 [-1]
Factor 4. Aeration			
Soil structure (in rooting zone)	Granular, porous; single-grained; or massive (if sandy, loamy, or silty); blocky [8]	Prismatic; platy [4]	Massive (if clayey) [-2]
Swampiness	Wet in winter only [8]	Wet January-July [4]	Waterlogged all year [Unsuitable]
Mottling	None to 18" depth [7]	None to 8" depth [5]	Mottled to surface [-2]
Soil color (A-horizon)	Black, brown, red [7]	Yellow, brownish-gray [4]	Gray [-2]

[1] Each bracketed number indicates the site quality rating (SQR) of a particular soil-site condition.

[2] If the soil is a sand or loamy sand, then [-10].

[3] If cultural practices included annual fertilization, then [4].

Field-plot data from Broadfoot (1976) were used by Baker and Broadfoot to test the technique for accuracy on a variety of soils and physiographic areas. Site index values estimated for a particular site by the new method were compared to measured site index values of Broadfoot (1976). These comparisons were subjected to correlation analysis and to the chi-square test of accuracy (Freese 1960). Correlation coefficients ranged from 0.93 for sweetgum to 0.99 for cottonwood. The chi-square test of accuracy indicated that the Baker and Broadfoot (1977) method should provide estimates of site index within 5 feet of measured values 99 percent of the time if all soil-site properties are accurately measured.

Besides providing a reliable estimate of site index, the technique also gives an indication of which major soil factor(s) is limiting tree growth. In the example discussed above, physical condition totaled 27 of a possible score of 30, or 90%; moisture availability, 24 of 36 possible (67%); nutrient availability, 12 of 24 (50%); and aeration, 30 of 30 (100%). There are no standards with which these percentages can be compared, but certain generalizations are possible. Aeration is excellent in this soil, and physical condition probably does not limit sweetgum growth. Moisture deficiency could be a problem, but nutrient availability is most likely the limiting factor.

SUMMARY

The subjective-objective approach of Baker and Broadfoot (1977) provides reliable estimates of productivity based on soil-site properties which are reasonably easy to identify in the field. Knowledge of soil series descriptions is not necessary. A few hours of instruction from a soil scientist should enable a land manager to apply the technique. The method can be applied over a range of geographic provinces and soil-site conditions. The approach may also provide general indications of factors limiting tree growth.

For the reasons mentioned earlier in this paper, the purely objective approach of Broadfoot (1969) does a relatively poor job of providing reliable site indices.

The subjective techniques (Broadfoot 1964b and 1976) are reliable but are limited to certain soil series, and ability to identify soils by series name is required, a major disadvantage overcome in the more recent technique of Baker and Broadfoot (1977).

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