Growth predictions for tree species planted on marginal soybean lands in the Lower Mississippi Valley

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*ABSTRACT: The establishment of bottomland hardwood forest stands and riparian buffers on frequently-flooded soybean (*Glycine max.*) lands in the Lower Mississippi Valley represents a tremendous opportunity to provide both economic and environmental benefits to the region. Selecting appropriate sites for reestablishing tree cover, accurately predicting the productivity of planted trees and optimally matching species to site are critical for the economic justification and implementation of tree planting in conservation programs.*

This study tests a low-cost methodology that incorporates the expert system developed by Baker and Broadfoot (1979) to predict tree growth rates calibrated with soils data from recently published Natural Resources Conservation Service (NRCS) soil surveys specific for combinations of tree species and soil series. This information is used to make site index projections for economically-marginal soybean lands. Site index estimates ranged from 28.0 m (92 ft) for cottonwood (base age 30) on Mhoon soils to 18.0 m (61 ft) for sycamore (base age 50) on Forestdale soils. Use of this method results in tree growth predictions that are both more mechanistically-based and often more conservative than the site index projections published in soil surveys, particularly for species intolerant of flooding during the growing season.

Key words: Bottomland hardwoods, CRP, Glycine max., Lower Mississippi Valley, marginal soybean lands, site index, soil survey, tree growth, tree planting, tree species-site relations.

The Lower Mississippi V&y contains bottomland hardwood-dominated forests that are among the most productive in the United States. Widespread conversion of forest land to agricultural uses occurred throughout the region over the past 200 years. Presently, forests cover less than one-quarter of the area of forestland prior to European settlement. Most recently, widescale loss of forest cover occurred during the early 1970s in response to increases in soybean prices (Sternitzke 1976). In many cases, these last forests to be cleared occupied sites which were too frequently flooded to support row-crop agriculture on a sustainable basis due to poor internal drainage, backwater flooding, or both. Changes in both soybean and forest products markets have rendered some of these lands economically marginal for soybean production. Changing economics, in combination with an increasing recognition of the environmental benefits of forested wetlands, have kindled widespread interest in converting marginal soybean land back to bottomland hardwood forests (Amnchrr et al. 1998). Accordingly, many of these lands are being enrolled in the Conservation Reserve Program (CRP), Wetlands Reserve Program and other cost-share programs involving forest establishment.

CRP landowners who elect to plant trees do so for a number of reasons, including enhancement of recreation, aesthetics, and wildlife values, as well as the eventual sale of forest products (Olmstead and McCurdy 1989). These benefits are realized soonest, and to the greatest extent, when the conversion from open cropland to closed forest canopy occurs rapidly (Hubbard end Lowrance 1997; Twedt and Portwood 1997). On-and off-site environmental benefits, such as nitrate and pesticide removal, streambank stabilization, and water temperature moderation also are accelerated through rapid reforestation. Maximizing tree and stand growth rates without increasing management costs generates stronger financial incentives to plant trees and may motivate landowners to keep cropland or riparian buffers in forest cover beyond the expiration date of current cost share programs. Realization of these objectives requires an understanding of the physical, chemical, and hydrological characteristics of the soil and site (Hodges 1997), and knowing the tree species most appropriate for those conditions.

Soil series-specific tree planting recommendations and growth rate predictions are given in county and parish soil surveys produced by the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS). This information is generally based on research conducted on cutover forest lands and does not reflect soil and site changes brought about by 20 or more years of soybean culture, including increased soil bulk density, lower organic matter content, reduced rooting volume, and altered nutrient availability (Francis 1984). Unfortunately, species-to-plant recommendations and predictions of potential tree growth rate based on data from former soybean lands are not yet available. It will be some time before the trees which were only recently planted on these lands are old enough to provide empirical growth and productivity estimates that overcome some of the confounding factors associated with stand establishment. A mechanistically-sound basis for making tree species-to-plant recommendations and growth estimates would aid tree planting efforts in the interim.

Baker and Broadfoot (1978, 1979) developed a species-specific method for predicting tree height attained at a given base age (site index) for several bottomland hardwood species by evaluating soil and site attributes important to tree growth. Previous research with cherrybark oak (*Quercus pagoda Raf.*) demonstrated the accuracy of this method (Aust and Hodges 1988; Bell et al. 1998). In the past, use of this system required intensive sampling of the proposed planting site. However, recently published soil surveys now include the necessary information on the physical and chemical properties of soil series. With these data, along with assumptions regarding soil and site characteristics of former soybean lands, height growth can be predicted for several tree species planted on any soil series within the southern hardwood region (Broadfoot 1976).

The objective of this study is to evaluate the use of Baker and Broadfoot's (1979) field-based method for marginal soybean lands using published soils data and generic assumptions regarding soil and site conditions. Comparisons are then made with species-to-plant and site index estimates published in soil surveys.

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Table 1. Baker and Broadfoot (1979) site **index** evaluation for cottonwood **using** assumptions of long-term aoybaan cultivation and Information from a **published soil** survey. Described here is en Amagon **soil with** data from the **USDA/NRCS** Soil Survey **Division Official Soil Series** Descriptions **(www.statlab.lastate.edu/soils/osd/).** The sum of underlined **point values** equals predicted site index in feat at a baae age of 30 years,

Soil-site property	Soil-bile condition and relative queiity: Best	Medium	Poor	Source of information
		Factor 1. Phyoioai condition		
Soil depth and presence of artificial or inherent pan	Deep soil (> 4 ft; without pan) (16)[z]	Medium depth (2-4 ft), or a soil with a plowpan (11)	Shallow soil (c 2 ft), or a soil with an inherent pan (-11)	Soil Survey, plowpan assumed to be disrupted by deep plowing
Texture (in rooting zone)	Medium-textured; silty or loamy (11)	Coarse-textured; sandy (8)	Fine-textured; clayey (-4)	Soil survey
Compaction (in surface foot)	No compaction; loose, porous, friable, bulk density < 1.4 g/cc (9)	Moderately compacted; flrm moderately tight, bulk density 1.4-l .7 g/cc (6)	Strongly compacted; tight, bulk density >1.7 g/cc (-3)	Soil Survey
Structure (in rooting zone)	Granular; structureless, single-grained if sandy, massive if loamy or silty (5)	Prismatic blocky (-3)	Massive (If clayey): platy (3)	Soil Survey
Past use and present covet	Undisturbed; near-virgin forest cover (5)	Moderate cultivation; cultivated c 20 yr, or open wlth grass cover (2)	Intensive cultivation; cultivated >20 yr, or open and bare (-2)	Assume intensive cultivation for >20 yr
		Factor 2. Moisture avaiiebiiity durlng growing season		
Water table depth	2-6 (10)	l-2': 7-10 (7)	1' (unsuitable); 10' (O)' .	Soil Survey
Artificial or inherent pans	No pans (9)	Plowpan (6)	Inherent pan (-6)	Soil Survey, plowpan assumed to be disrupted by deep plowing
Topographic position	Floodplain or stream bottom (7)	Stream terraces or lower slopes (5)	Upland (-5)	Soil Survey
Microsite	Concave; depresslon, pocket, trough (7)	Level: flat (5)	Convex:ridge, mound (-2)	Assumed to be flat due 10 leveling associated with cultivation
Structure (In rootlng zone)	Granular: structureless, massive (If silty, loamy, or clayey); stratified (5)	Prismatic; blocky (if sandy); platy (3)	Structureless, single-grained (-3)	Soil Survey
Texture (in rooting zone)	Silty or loamy (or stratified) (4)	Clayey (2)	Sandy (-2)	Soil Survey
Flooding	Winter through Spring (2)	Winter only (1)	None (-1); continuous (unsuitable)	Soil Survey
Past use and present cover	Undisturbed; near-virgin forest cover (2)	Moderate cultivation cultivated <10 yr or open with grass cover (1)	intensive cultivation cultivated > 10 years or open and bare (-1)	Assume intensive cultivation > 10 years

Table 1 cont.

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

Methods

Selection of soils and species. The criteria for selection of the 10 Lower Mississippi Valley soil series were:

1. Soybean farming is commonly practiced on the series.
2. At least some phases of the series are classified as poorly or somewhat poorly drained.
3. Flooding frequency ranges from occasional to frequent.
4. The soil series is classified as hydric (Soil Conservation Service 1987).

All series used in this study met each of these criteria except Dundee, which is not hydric, but commonly occurs in association with several of the other selected soil series. Tree species were selected for evaluation on their adaptation to bottomland sites and potential merchantability, and included the following: Eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.), green ash (*Fraxinus pennsylvanica* Marsh.), Nuttall oak (*Quercus nuttalli* Palmer), swamp chestnut oak (*Q. michauxii* Nutt.), water oak (*Q. nigra* L.), sweetgum (*Liquidambar styraciflua* L.), and sycamore (*Platanus occidentalis* L.).

Site index estimates. Soil series and species-specific site index estimates were made using the method developed by Baker and Broadfoot (1979). For each species, 23 soil and site characteristics were assigned one of three point values representing conditions thought to be good, fair, or poor for tree growth (Table 1). Species specific estimates are made by weighting point values to reflect the relative importance of each criterion to the growth of a particular species, as well as that species maximum attainable site index. The sum of these weighted point values provides an estimate of site index (tree height at a given base age) for a tree species under the specified soil series and site conditions. Site index values use a base age of 50 years for all species presented here, except cottonwood where the conventional base age is 30 years.

In this study, site index estimates for seven southern bottomland hardwood tree species on each of 10 Lower Mississippi Valley soil series were made by calibrating the models of Baker and Broadfoot (1979) with soil chemical, physical, and hydrological data drawn from the general soil series descriptions at the NRCS web site (18 variables) (Table 1). Values for the remaining five variables were assigned on the basis of

Table 2. Site index predictions (m) based an Baker and Broadfoot (1979) for seven hardwood tree specie6 for soil serles likely to support marginal soybean agriculture in the Lower Mississippi Valley. Note that polnt values differ by rpeoies due to inherently differing resource needs, toierancee, and growth rates.

Soil series	Cottonwood	Green ash	Nuttall oak	Swamp chestnut oak	Sweetgum	Water oak	Sycamore
Alligator	23.2	22.0	24.4	20.1	23.8	21.9	22.9
Amagon	27.1	23.2	25.3	22.3	25.0	23.5	25.0
Bowdre	22.3	22.6	23.5	19.6	23.6	21.6	21.6
Dundee	27.7	24.1	25.3	21.9	26.6	24.4	25.0
Forestdale	24.1	21.6	23.2	19.5	21.6	19.8	16.0
Mhoon	28.0	23.8	25.0	20.7	23.2	21.0	21.6
Neweiiton	24.4	23.5	24.7	20.1	24.7	21.9	23.2
Sharkey	22.9	21.9	23.8	20.1	22.9	21.3	21.3
Tensas	22.6	22.3	24.1	20.1	23.2	21.9	21.3
Tunica	22.9	21.6	23.5	18.6	22.3	19.5	18.6
Standard deviation	2.11	0.85	0.74	1.03	1.41	1.41	2.21

. Base age for cottonwood is 30 years. 50 years for ail other species.

Table 3. Percent difference between Baker and Broadfoot (1979) site index estimate6 for marginal soybean lands in the Lower Mississippi Valley and those included in NRCS Soil Survey species-to-plant reccmmendaticna for five bottomland hardwood tree species. P-values were obtained ueing a paired t-test comparing site Index values from the two aforementioned predictors.

Soil series	Cottonwood	Green ash	Nuttall oak	Sweetgum	Water oak
Aiilgator	-16	+6	—	-3	-20
Amagon	-11	-5	-17	-16	-23
Bowdre	-34	—	—	-18	-25
Dundee	-9	—	—	-12	-16
Forestdale	-21	-9	-20	-25	-28
Mhoon	-16	-13	—	-24	
Naweiiton	-20	+3	-5	-15	-20
Sharkey				-17	-22
Tensas				-24	-24
Tunica		—	—	-19	—
p value	0.001	0.01	0.04	0.0001	0.0001

assumptions made for economically marginal soybean lands of the region (Table 1). Species-to-plant recommendations and projected site indices were collected from published USDA Soil Conservation Service/NRCS county and parish soil surveys within a 62-county/parish area of Arkansas, Louisiana, and Mississippi in the lower Mississippi Alluvial Plain (Groninger ct al., *In Press*).

Results and discussion

Site index estimates ranged from 28.0 m (92 ft) for coeconwood (base age 30) on Mhoon soils to 18.0 m (61 ft) for sycamore (base age 50) on Forestdale soils (Table 2). Silt loam soils (Amagon and Dundee series) typically showed higher sire indices than rhc other series, which were predominantly of clay texture. Among the tree species used in this study, green ash and Nuttall oak sire index estimates varied least between soil types. The relatively rapid growth across all soils is consistent with rhe recognition among foresters that these species arc well adapted to a wide range of frequently-flooded soil types. Sycamore and cottonwood varied most among soil series consistent with their sensitivity to soil and site condirions. Therefore, identification of suicablc soil and site condirions is especially important when considering these species for reforestation.

Site index values calculated using Baker and Broadfoot (1979) were significantly lower than values given Fnr species recommended for planting in soil surveys (Table 3) with differences typically in the IO to 20% range. Green ash was an cxceprion on Alligator and Newellton soils where cstimares of site index were lower than published soil sutvcy values, reflecting rhc recognized rolcrance of green ash to poor soil condirions and highly-disturbed sites throughout the region. Cottonwood site index estimates varied less for soils of silt loam than for clay textures, suggesting that row crop agriculrurc may have a lesser impact on these soils. Maintenance of better inrcrnal drainage and consequently, a deeper rooting zone following disturbance is likely an important consideration in the predicted success of cottonwood on the silt loam soils.

Diffcrcnces between soil survey values and our estimates based on Raker and Broadfoot (1379) likely reflect differences in assumptions made regarding soil and site conditions. Estimates included in soil surveys were derived from naturally-regenerated, well-stocked forest stands wirh no evidence of recent cutting or burning (Francis 1984). Predictions using rhc Baker and Broadfoor (1979) guide incorporated likely changes in soil and sire conditions associated with long-term row crop cultivation. For instance, agricultural soils arc characterized by higher bulk density, lower soil organic matter content, altered fertility, and sometimes smaller available rooting volume caused by restrictive plowpans (Francis 1985; Stanturf et al. 1998). However, the shrink-swell clay mineralogy and previous agricultural amendments may teducc rhe impact of these impediments. Site preparation and post-establishment management practices, including weed control treatments, fertilizer applications. fallowing, and deep plowing, have been recommended IO ameliorate the adverse effects of long-term agronomic practices (Allen 1990; Baker and Blackmon 1978; Blackmon and Whire 1972; Francis 1985).

Perhaps the greatest value of this adaptation of Baker and Broadfoot (1979) for land managers is the incorporation of more specific tree growth estimates into the species selection process. Failure to correctly march species and site has consequences ranging from sub-optimal stand productivity LO complcre planting failure. While site index estimates obtained through the use of the Baker and Broadfoor (I 979) method appcat to bc an improvement over those published in soil surveys, they cannot be used in isolation to make recommendations for the appropriateness of a certain tree species on a particular site. Baker and Broadfoot (1979) provide guidance on profitability for timber management that goes beyond site adaptation. Their recommendations reflect silvicultural practices and hardwood markets 20 years ago, and probably arc no longer valid. For example, their productivity crircria suggest that cottonwood may bc managed on Amagon, Dundee, Mhoon, and Newellton soils formerly in soybean production, but nor on any of the other series included in this study. However, recent improvements in cottonwood pulpwood markets and advances in competition control permit the successful management of this species on a 10-year rotation on formerly row-cropped Sharkey soils (Stanturf et al. 1998).

The dynamic nature of hardwood markets and continual advances in bottomland hardwood silviculrure indicarc a need for flexible management decision systems. New techniques arc cmcrging, such as using cottonwood as a nurse crop for inrcrplanred Nuttall unk (Schwciczcr et al. 1997). Monitoring the growth and maturation of these and other recent plantings on former agricultural lands can serve as the basis for empirically-derived models of stand growth rate and productiviry that will provide bcrrcr spccics planting recommendations. Further work should focus on dcrcrmining site index using younger base ages to reflect the increasing utilization of smaller trees.

Conclusions and recommendations

Until empirically-based guides are available, the mcrhod of Baker and Broadfoor (1979) rcprcscnrs the best available cool Fur tree species selection and growth prediction. Ideally, application of this merhod to a particular site should include an on-site evaluation *by* a soil scientist or silviculturist. as well as an understanding of site flooding regimes. If this is not possible, wc suggest application of the approach described here using soil survey soil data in appropriate regions of the southern United States.

Although the Baker and Broadfoot method was originally developed as a site-specific silvicultural tool, it may he useful to regional land use and economic planners wherever southern bottomland hardwoods are planted. Overlaying these site index estimates and soil series data in a geographic information system can provide estimates of the conrriburiun of reforestation to environmental remediation and long-term forest-based economic development. Further, reforestation efforts may be focused on marginal agricultural lands where forest productivity and associated economic and environmental benefits arc optimized (Luvejoy et al. 1985). Modification of rhc Baker and Broadfoot (1979) method to conditions in orhcr regions could hcilirarc thr broader USC of this tool in land use policy and program decisions.

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