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GROWTH AND DEVELOPMENT OF FOUR OAKS THROUGH AGE 10 PLANTED AT FIVE SPACINGS IN A MINOR STREAM BOTTOM

Harvey E. Kennedy, Jr., Roger M. Krinard, and Bryce E. Schlaegel[1]

Abstract.--The growth and development of four species of oak, planted at five spacings in a minor stream bottom in southeast Arkansas, illustrate differences among species and by spacing. Spacing and species affected all tree size and biomass variables except survival. Water oak developed most rapidly, while swamp chestnut oak developed most slowly. Ten-year results show that all four oak species can be grown successfully at any of the tested spacings.

Additional keywords: Biomass, artificial regeneration, Quercus nigra, biomass distribution, dry weights.

INTRODUCTION

Worldwide demand for wood products is increasing, along with demand for recreational and watershed uses of forest lands. While these demands are increasing, large areas of prime hardwood and pine forest lands are being cleared for agriculture, urban and industrial development, highways, and utility rights-of-way. Plantations of oaks can provide great quantities of biomass. However, plantations are expensive to establish and results can vary by species and spacing. This paper reports quantitative 10-year data on tree growth and development of four oak species planted at five spacings in a hardwood plantation.

TEST SITE

The test site was a 10-year-old hardwood plantation growing in a minor stream bottom 10 miles south of Monticello in southeastern Arkansas. Four oak species were planted at five spacings in a randomized complete block design. The species were: water oak (Quercus nigra L.), Nuttall oak (Q. nuttallii Palmer), cherrybark oak (Q. falcata var. pagodifolia Ell.), and swamp chestnut oak (Q. michauxii Nutt.). There were 4 blocks of each of the possible 20 factorial spacing and species combinations.

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[1]Harvey E. Kennedy, Jr., is Principal Silviculturist and Roger M. Krinard is Mensurationist at the Southern Hardwoods Laboratory, maintained at Stoneville, Mississippi, by the Southern Forest Experiment Station, Forest Service--USDA, in cooperation with the Mississippi Agricultural and Forestry Experiment Station and the Southern Hardwood Forest Research Group; Bryce E. Schlaegel is Regional Mensurationist, Southern Region, Forest Service--USDA, Atlanta, Georgia.

Each plot consisted of 169 trees planted in a rectangular grid of 13 by 13 rows. The interior 5 by 5 rows were designated as permanent remeasurement rows, with the outer 4 rows as a buffer.

The soil series was Arkabutla, a member of the fine-silty, mixed, acid, thermic family of Aeric Fluvaquents. Formed in silty alluvium, these somewhat poorly drained soils have dark-brown silt loam A horizons (surface layers) and dark-brown silty clay loam upper B horizons (subsoils) underlain by light brownish-gray silt loam. Estimated site indices for the four oaks range from 90 ft at age 50 for swamp chestnut oak to 110 ft at the same age for Nuttall (Broadfoot 1976). The plantation was established on an area recently cleared of a mature, natural, mixed hardwood stand. The area was then prepared for planting by shearing, root raking, and disking. The plantation was disked four or five times during the first growing season.

The spacings in feet and respective number of trees per acre (in parentheses) were 2 by 8 (2,723), 3 by 8 (1,815), 4 by 8 (1,361), 8 by 8 (681), and 12 by 12 (303). Spacings were chosen to span from narrow coppice to the more usual pulpwood and saw log spacings. The 8-ft distance between rows was chosen to allow cultivation with standard farm equipment during the first growing season.

METHODS AND MATERIALS

Beginning in the fall of 1977, two trees from each plot were destructively sampled each fall. Trees were from the second and third buffer rows on three of the previously established four blocks. The same three blocks were sampled annually for 10 years, yielding a total of 10 samples. Because it was impractical to sample all plots, the blocks were chosen primarily on the basis of high survival at age 3. Additionally, tree heights, diameters at breast height, and survival were measured, and soil samples were obtained each year on all plots in each of the four blocks.

Field measurements on the destructively sampled trees included diameter 6 inches above groundline, d.b.h., total height, height to live crown, total bole weight, and total crown weight. Individual bole, limb, and leaf samples were taken and sealed in polyethylene bags for laboratory determinations of green and dry weights and volume. Two 1-inch-thick disks were cut from the bole at a 6-inch stump and at intervals of 20, 40, 60, and 80 percent of total tree height for growth and chemical determinations.

The branch and leaf samples were obtained by selecting two representative branches from each quarter of crown length and consolidating them into an 8-branch tree sample; leaves were detached from the branches in the field and bagged separately. Green weights, dry weights, and volumes of bole and branch components were determined in the laboratory by standard laboratory procedures from a representative sample of the eight branches; the remainder of the sample was used for chemical analyses.

Green weights of bole wood and bark for each tree were obtained by multiplying the proportion of each component in the bole sample times the total bole green weight measured in the field. Green weights of branch wood,

branch bark, and leaves were derived by adding the leaf and branch sample weights, finding the proportion of each component in the sample, and applying the proportions to the total crown weight obtained in the field.

Total dry weights and volumes for each component were calculated by using the moisture contents of the consolidated sample component and their specific gravities. Moisture contents and specific gravities were assumed to be uniform within each component.

STATISTICAL ANALYSES

A randomized complete block design was used with four replications. The 20 treatments—4 species by 5 spacings—occurred at random within blocks to fit the spaces available. For analyses, treatments were divided into species, spacing, and species by spacings interactions. Testing was at 0.05 level. Comparisons among treatment means were made using Duncan's new multiple range test.

RESULTS AND DISCUSSION

All statistical analyses and discussion are based on measurements made after 10 growing seasons in the field. However, to illustrate the trends of tree development, data for years 2, 4, 6, 8, and 10 are included.

Diameters at breast height and total height

Both spacing and species significantly affected d.b.h. and height growth. Data for these two variables are shown in Table 1. Averaged over all species, the 2- by 8-ft and the 3- by 8-ft spacings produced the significantly smallest d.b.h. trees, while the largest d.b.h.'s were in the 12- by 12-ft spacing (Table 2). Although the d.b.h. of the trees in the 4- by 8-ft and 8- by 8-ft spacings were between the above values, d.b.h.'s were not significantly different from each other. Averaged over species, d.b.h.'s ranged from 1.7 inches in the 2- by 8-ft to 3.1 inches in the 12- by 12-ft spacing. Water and Nuttall oak had the largest d.b.h. and swamp chestnut oak the smallest (Table 2).

The tallest trees were in the 4- by 8-ft and 12- by 12-ft spacings and the shortest were in the 2- by 8-ft and 3- by 8-ft spacings (Table 2). Although the heights of the trees in the 8- by 8-ft spacings were between the above values, the heights were not significantly different from those in the narrower or wider spacings. Water oak had significantly taller trees at 23.9 ft than the other three species (Table 2).

Averages for all trees are shown in Tables 1 and 2. These averages may not give a complete picture of growth and development because only a few small trees can cause a large reduction in the average of many larger trees. Therefore, a sample representing the 100 largest trees per acre were collected from each plot in the 3- by 8-ft, 8- by 8-ft, and 12- by 12-ft spacings that best represent the final crop trees. The spacings were picked because they

Table 1.--Diameters and heights by species and spacings through age 10.

Years	2x8		3x8		4x8		8x8		12x12	
	Dia.	Ht.	Dia.	Ht.	Dia.	Ht.	Dia.	Ht.	Dia.	Ht.
	in.	ft.	in.	ft.	in.	ft.	in.	ft.	in.	ft.
					Water Oak					
2	0.28	4.8	0.24	4.7	0.22	4.9	0.30	5.2	0.29	4.8
4	0.75	9.8	0.71	9.0	0.74	9.5	0.88	9.9	0.90	9.3
6	1.29	14.8	1.26	14.5	1.50	16.2	1.60	15.5	1.87	16.1
8	1.68	18.3	1.69	17.8	2.11	20.7	2.22	20.0	2.94	21.4
10	2.01	21.7	2.05	21.5	2.59	24.4	2.78	25.0	3.96	26.7
					Nuttall Oak					
2	0.20	3.4	0.18	2.7	0.16	3.7	0.21	3.9	0.27	3.9
4	0.61	7.5	0.46	6.1	0.73	8.3	0.63	7.4	0.79	8.2
6	1.21	11.8	1.18	11.3	1.51	13.3	1.36	11.4	1.69	13.1
8	1.63	16.0	1.79	16.1	2.10	17.2	1.87	14.7	2.52	17.4
10	1.88	19.6	2.39	21.1	2.56	21.5	2.64	18.2	3.32	22.6
					Cherrybark Oak					
2	0.24	3.2	0.32	4.3	0.26	4.4	0.34	3.9	0.39	4.0
4	0.60	6.7	0.63	7.7	0.82	8.4	0.76	7.7	0.80	7.6
6	1.00	11.1	1.00	11.5	1.42	13.4	1.41	12.1	1.52	11.6
8	1.41	14.8	1.39	14.7	1.91	17.2	2.01	16.2	2.33	16.2
10	1.79	19.0	1.68	17.3	2.36	21.6	2.53	20.4	3.11	21.6
					Swamp Chestnut Oak					
2	0.35	3.1	0.27	2.2	0.33	3.7	0.27	3.2	0.23	2.1
4	0.41	5.5	0.30	4.3	0.52	6.2	0.41	5.5	0.31	4.4
6	0.72	8.0	0.50	6.3	0.87	8.9	0.83	8.1	0.65	7.3
8	1.11	9.9	0.79	8.7	1.26	11.6	1.22	10.8	1.29	10.0
10	1.16	12.1	1.17	10.8	1.60	14.3	1.66	13.4	2.01	13.9

Table 2.--Means for d.b.h., heights, survival, total tree dry weight without leaves, and leaf dry weights after 10 years[1]

Variable	Spacing (ft.)				
	2x8	3x8	4x8	8x8	12x12
D.b.h. (in.)	1.7c[2]	1.8c	2.1b	2.4b	3.1a
Height (ft.)	18.1b	17.7b	20.5a	19.3ab	21.2a
Survival (%)	69	73	77	68	78
Tree wt. (t/A)	20.8a	16.9a	19.7a	9.9b	8.6b
Leaf wt. (t/A)	2.5a	2.6a	2.3a	1.1b	0.9b

Variable	Species			
	Swamp chestnut oak	Cherrybark oak	Nuttall oak	Water oak
D.b.h. (in.)	1.5c	2.3b	2.6ab	2.7a
Height (ft.)	12.9c	20.0b	20.6b	23.9a
Survival (%)	71	73	69	78
Tree wt. (t/A)	6.4c	14.1b	16.4b	23.8a
Leaf wt. (t/A)	1.0c	1.7b	2.0ab	2.3a

[1]Spacing averaged over all species and species over all spacings.
[2]Means in a row followed by the same letter are not significantly different at the 0.05 level; if no letters, overall test was not significant.

contained both the smallest and largest trees as well as those of intermediate size (Table 1). Average d.b.h.'s and heights for the 100 largest trees per acre were calculated. These averages and the increase over averages for all trees in a spacing are given in Table 3.

The increases were generally 1 to 2 inches in diameter and 5 to 10 ft in height. Increases were also generally greater in the narrow spacings than the wider ones. This difference appeared to result from a few dominant trees per plot in the narrow spacings. Because of the small plot size, by age 10 the trees were dominating the area. At the wider spacings, trees still had more room to grow.

Survival

Survival was not significantly affected by either spacing or species (Table 2). Most mortality occurred within the first 2 years after plantation establishment. Only an occasional tree was lost during the last 8 years.

Table 3.--Average d.b.h. and height of 100 largest trees per acre and the increase over averages of all trees

Spacing	Water oak		Nuttall oak		Cherrybark oak		Swamp chestnut oak	
	Dia.	Ht.	Dia.	Ht.	Dia.	Ht.	Dia.	Ht.
	in.	ft.	in.	ft.	in.	ft.	in.	ft.
3x8	3.8	31.2	3.8	29.3	2.9	24.4	2.3	16.3
Increase	1.7	9.7	1.4	8.2	1.2	7.1	1.1	5.5
8x8	3.7	29.8	3.6	23.2	3.6	26.3	3.0	20.8
Increase	0.9	4.8	1.0	5.0	1.1	5.9	1.3	7.9
12x12	5.5	32.6	4.7	26.8	4.6	27.7	2.5	16.6
Increase	1.5	5.9	1.4	4.2	1.5	6.1	0.5	2.7

Woody tree material and leaf biomass

Tree and leaf dry weights were both significantly affected by spacing and species (Table 2). Data by species, spacing, and years are shown in Table 4. The greatest woody material biomass was produced in the three most narrow spacings; the lowest amount was produced in the two wider spacings (Table 2). Tree dry weights, averaged over species, ranged from 20.8 dry tons per acre after 10 years in the 2- by 8-ft spacing to 8.6 tons per acre in the 12- by 12-ft spacing. Averaged over all spacings, water oak produced 23.8 dry tons per acre of woody biomass, while swamp chestnut oak produced only 6.4 tons. Nuttall and cherrybark oak were between these two extremes, but were not significantly different from each other (Table 2). For people who work with green weights, the green weights were approximately two times greater than dry weights shown in all the tables.

Dry leaf weights followed basically the same pattern as woody material (Table 2). The greatest leaf weights were produced in the three narrow spacings that did not differ statistically, while significantly lower weights were produced in the two wider spacings. Water oak produced the greatest weight in leaves and was significantly greater than cherrybark and swamp chestnut oak (Table 2). The leaf weight of Nuttall was between the values for cherrybark and water oak and was not significantly different from either species. Weights ranged from a high of 2.6 tons dry leaves per acre per year in the 3- by 8-ft spacing to a low of 0.9 tons in the 12- by 12-ft spacing. Water oak again had greatest leaf weights at 2.3 tons dry leaves per acre, while swamp chestnut oak was lowest at 1.0 ton per acre.

Mean annual increment (m.a.i.) for water oak continued to increase annually through age 10 (Figure 1). Growth was slow for the first 2 or 3 years, and then m.a.i. increased more rapidly. In the more narrow spacings, growth was slower in the last 2 years but was still increasing at a good rate

Table 4.--Tree dry weights per acre without leaves and dry leaf weights by species and spacing.

Years	2x8		3x8		4x8		8x8		12x12	
	Tree	Leaf	Tree	Leaf	Tree	Leaf	Tree	Leaf	Tree	Leaf
	tons									
					Water Oak					
2	0.7	0.3	0.5	0.2	0.4	0.2	0.3	0.1	0.1	0.1
4	4.8	0.9	3.4	0.7	2.6	0.5	2.1	0.4	1.1	0.2
6	13.9	2.0	11.5	1.6	10.1	1.4	6.7	0.9	4.1	0.5
8	22.2	2.6	18.2	2.1	18.4	2.1	12.0	1.4	8.4	0.9
10	30.3	3.1	27.5	2.7	27.1	2.7	18.4	1.8	15.8	1.4
					Nuttall Oak					
2	0.2	0.1	0.1	0.1	0.2	0.1	0.1	0.0[1]	0.1	0.0
4	2.2	0.5	1.0	0.2	1.7	0.4	0.5	0.1	0.6	0.1
6	8.0	1.4	5.0	0.8	7.5	1.2	1.7	0.3	2.6	0.4
8	14.8	2.2	11.7	1.6	14.2	1.9	3.1	0.4	5.1	0.6
10	23.5	3.1	20.7	2.5	23.3	2.8	5.2	0.6	9.2	1.0
					Cherrybark Oak					
2	0.3	0.2	0.4	0.2	0.4	0.2	0.2	0.1	0.1	0.0
4	2.0	0.5	2.0	0.5	2.3	0.5	1.1	0.3	0.5	0.1
6	6.6	1.2	5.5	1.0	7.3	1.2	3.8	0.6	1.8	0.3
8	11.9	1.7	9.6	1.4	13.1	1.7	6.7	0.9	3.8	0.5
10	19.1	2.3	13.8	1.8	20.7	2.3	10.4	1.2	6.6	0.8
					Swamp Chestnut Oak					
2	0.4	0.1	0.1	0.0	0.3	0.1	0.1	0.0	0.0	0.0
4	1.9	0.4	0.4	0.1	1.0	0.2	0.5	0.1	0.1	0.0
6	4.7	0.8	2.0	0.3	2.9	0.5	1.7	0.3	0.5	0.1
8	7.4	1.1	3.4	0.6	4.9	0.8	3.5	0.6	1.2	0.2
10	10.3	1.5	5.6	0.9	7.7	1.2	5.5	0.9	2.7	0.5

[1]Less than 0.1 ton.

in the two wider spacings. After 10 years, m.a.i. ranged from a high of 3.0 dry tons per acre per year for water oak in the 2- by 8-ft spacing to a low of 1.6 dry tons per acre in the 12- by 12-ft spacings. Growth was slightly lower in Nuttall and cherrybark oak, but growth patterns were similar to those found in water oak. Swamp chestnut oak was different because it grew very slowly the first 6 to 7 years and accelerated during the last 3 to 4 years. It presently grows similarly to the other three oaks.

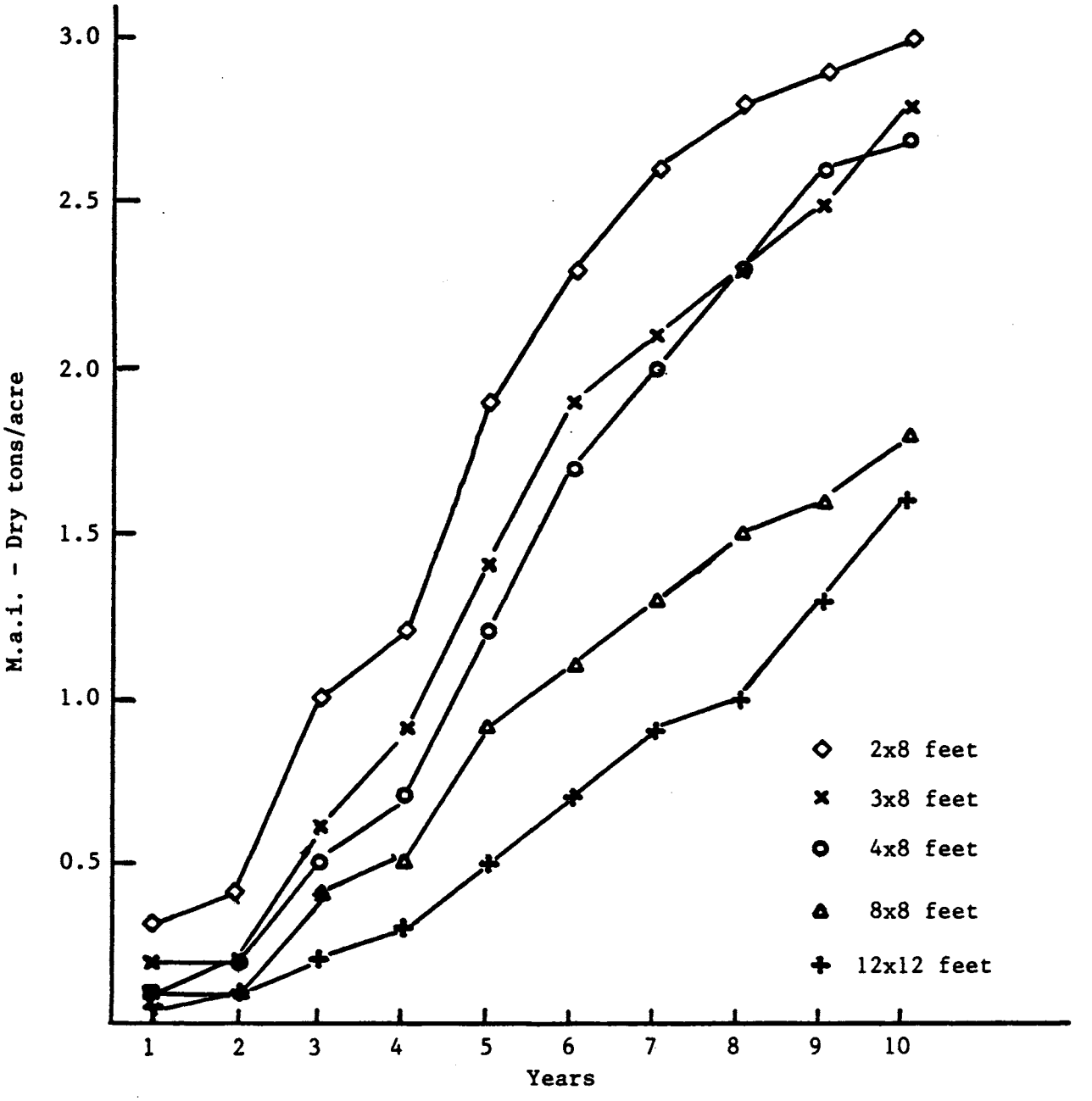

Figure 1.--Mean annual increment (m.a.i.) by spacing for water oak through age 10.

Biomass distribution among tree components

The distribution of biomass in the components of bole wood, bole bark, limb wood, limb bark, and leaves differed among species. Data for these components for two spacings are shown in Table 5; values for the 3- by 8-ft and 4- by 8-ft spacings were very similar to the 2- by 8-ft spacing. Likewise, the 8- by 8-ft and 12- by 12-ft spacings were about the same. Both spacing and species significantly affected the biomass distribution among the five components at age 10. Water oak had the significantly lowest percentage in bole wood. The other three species were not different from each other in percentage of tree in bole wood. Water oak had the highest percentage in limb wood, while swamp chestnut and cherrybark had the lowest (Table 5).

The three narrow spacings had significantly higher percentages of total weights in bole wood than the wider spacings. Conversely, because of a larger number of limbs and limb sizes, the highest percentages of limb wood occurred in the wider spacings, and the lowest percentages were in two narrow spacings. The number of branches per tree, averaged across species, ranged from 26 in the 2- by 8-ft to a high of 43 in the 12- by 12-ft spacing.

Averaged over all spacings, cherrybark had a significantly higher percentage of total weight in bole bark; Nuttall and swamp chestnut oak had the lowest percentages. Swamp chestnut oak had the highest percentage in limb bark and cherrybark the lowest. Numerically, the percentages in bole bark increased slightly over the 10-year period while percentages in limb bark decreased. The increase in bole bark percentage indicated that the bole surface area was probably increasing at a faster rate than in the limbs.

The ratio of leaf weight to whole tree weight without the leaves is shown in Table 5. In the early years of the plantation, leaves comprised a high proportion of the total aboveground biomass. However, as the trees grew larger, the proportion in leaves dropped rapidly. During the last 2 to 3 years, leaf ratios stabilized. Leaves presently comprise 10 to 15 percent of the aboveground dry biomass.

SUMMARY AND CONCLUSIONS

The study area, compared to other good bottomland hardwood sites such as Commerce silt loam, would be rated relatively infertile for hardwoods. The level of soil nutrients was poor, particularly for potassium, phosphorus, and calcium. The nutrients were below or barely reaching the acceptable level for good tree growth (Davey 1976, Broadfoot 1976). Even though the soil fertility level was classified low, growth of the four oaks during the 10-year period was good. Swamp chestnut oak was the slowest growing species. This could be a reflection of the slow growth during the first 5 or 6 years of the small seedlings available for planting. During the last 3 to 4 years, swamp chestnut oak was growing faster, and its rate was almost as good as the other three species.

Based on this study, any of these four oaks could be successfuly grown at the five spacings tested. Choice of spacing would depend on the product objective of the grower. Aboveground dry biomass yields are two to three

Table 5.--Percentage of dry tree weights without leaves in four components and ratio of leaves to whole tree without leaves for two spacings.

Years	2x8					12x12				
	BW[1]	BB	LW	LB	Lv. ratio[2]	BW	BB	LW	LB	Lv. ratio
	%					%				
Water Oak										
2	41	8	40	10	46	39	8	43	10	36
4	42	9	41	8	21	37	8	47	8	19
6	41	10	41	8	14	37	9	46	8	13
8	42	10	40	7	12	37	9	47	7	11
10	43	11	39	7	10	36	9	47	7	9
Nuttall Oak										
2	43	7	38	12	55	50	8	28	9	39
4	51	8	32	8	25	53	9	27	7	20
6	51	9	32	7	17	52	9	29	7	15
8	51	9	32	7	15	51	9	31	7	13
10	51	9	33	7	13	50	8	33	7	11
Cherrybark Oak										
2	47	9	34	10	61	43	9	39	9	44
4	49	11	33	8	28	42	9	41	8	24
6	50	11	32	7	18	42	9	41	7	18
8	51	12	30	6	14	44	10	39	7	14
10	53	13	28	6	12	46	11	37	6	12
Swamp Chestnut Oak										
2	50	10	29	11	62	50	11	29	11	58
4	57	11	25	8	27	57	11	24	8	26
6	58	10	25	7	19	57	10	26	7	18
8	56	10	27	7	17	53	9	30	7	17
10	55	10	29	6	16	46	8	38	8	17

[1]Component: BW = bole wood, BB = bole bark, LW = limb wood, LB = limb bark.
[2]Leaf weight/tree weight without leaves.

times larger at the more narrow spacings, but average diameters are twice as large in the wider spacings. There are nine times more trees in the 2- by 8-ft spacing, and planting costs are considerably higher than in the 12- by 12-ft spacing. Based on the results of this study, the three close spacings could be used if total biomass production was the objective. Because of the slow growth during the last 2 to 3 years in the more narrow spacings, the trees should not be allowed to grow longer than 10 years. It would be economically feasible to clearcut these spacings at age 10 and let them reproduce by coppicing. At the wider spacings, trees are still growing well, and final crop trees should be able to be carried to a saw log rotation with properly timed thinnings.

Spacing and species affected all tested tree size and biomass variables except survival. Leaves and bark comprised one-fourth to one-third of the aboveground biomass. Since these components contain a high proportion of the nutrients found in the aboveground biomass (Kennedy et al. 1986), any harvesting system that returns leaves and some bark to the site would return a large proportion of the nutrients to the soil and thus contribute to long-term maintenance of site quality.

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