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Ten-Year Results In a Cottonwood Plantation Spacing Study

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TEN-YEAR RESULTS IN A COTTONWOOD PLANTATION SPACING STUDY

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During the first 10 years, unthinned cottonwood planted at four spacings grew from 2.8 to 3.4 cords per acre per year in trees 5.0 inches in d.b.h. and larger. Two basal area controlled thinning treatments did not increase yields. Initial spacings were 4 by 9, 8 by 9, 12 by 12, and 16 by 18 feet on Commerce-Convent soils. Only trees at the widest spacing averaged an inch of diameter growth annually for the 10 years.

Additional keywords: *Populus deltoides*, thinning, growth and yield.

Cottonwood is the fastest growing tree in the South and a valuable veneer, lumber, and pulp species. An estimated 40,000 to 50,000 acres of eastern cottonwood (*Populus deltoides* Bartr.) have been planted in the lower Mississippi River Valley. Initial tree spacings were generally 9 by 9 or 10 by 10 feet. At these spacings, the trees were expected to reach pulpwood size by the first thinning, to require no pruning, and to provide adequate stocking even if only two-thirds survived. Such spacings were the minimum in which traditional farm equipment could be used in first-year mechanical cultivation.

The effects of spacing and subsequent stand manipulation on cottonwood growth is not known. This paper covers the first 10 years of a study to determine the relationship of diameter and volume growth to initial spacing and basal area control of stocking in cottonwood plantations.

METHODS

Twenty-inch run-of-the-bar cuttings were planted in January 1963 at spacings of 4 by 9, 8 by 9, 12 by 12, and 16 by 18 feet. Each increase in spacing halved the number of trees per acre. To obtain as high survival as possible, two cuttings were planted 4 to 6 inches apart at each planting spot. Where both cuttings sprouted, one tree was cut after the first year.

Measurement plots were 144 feet square and were surrounded by 50-foot buffer or isolation areas. There were eight plots per spacing.

The soils are medium textured and predominately Commerce and Convent. Commerce is fine-silty with from 18 to 35 percent clay in the top 40 inches; Convent is coarse-silty with from 10 to 18 percent clay. Both soils are classed as somewhat poorly drained. For natural stands of cottonwood on these soils, Broadfoot (1960) estimates a site index of 118 to 122 feet at age 30.

The study area had been in pasture for a number of years and was pan plowed to a depth of 14 inches before planting. Cultural treatments consisted of disking and scratching during the first year to control Johnsongrass. Several hoeings were also done on the 4 by 9 spacings after cross-scratching was stopped because of the height of the cottonwood. From the second year on, plots were mowed in late summer to knock down the Johnsongrass, weeds, and invading trees—predominantly boxelder.

Within each spacing, four thinning treatments were randomly assigned to the four plots with the highest basal areas and to the four with the lowest basal areas after 4 years. The thinning treatments were to reduce basal area per acre to 40, 65, 90, or 115 square feet whenever these values were exceeded by 15 square feet or more. Through 10 years, none of the plots achieved a basal area of 130+ square feet; therefore, the two plots per spacing scheduled to be thinned when they reached this level were never cut, and they served as unthinned checks (figs.1 and 2). Of the eight plots scheduled to be thinned when they reached basal areas of 105+ square feet,

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Figure 1.—*General view of check plots after 10 years: upper left—4 by 9 spacing, upper right—8 by 9, lower left—12 by 12, lower right—16 by 18.*

Figure 2.—*Crown development within the check plots after 10 years: upper left—4 by 9 spacing, upper right—8 by 9, lower left—12 by 12, lower right—16 by 18.*

four (those in the 12 by 12 and 16 by 18 spacings) never reached the 105+ level and served as additional checks; and four (those in the closer spacings) only reached the 105+ level after 9 years and are therefore not considered in this paper.

Thinning was done on a single tree selection basis. First the obviously weak, poorly formed trees were removed. Then spacing became a major consideration. In nearly all cases, plots were thinned after crown shapes had formed, but there was little chance of selecting for crown shape or size since most trees within a spacing treatment developed in a similar manner.

Plots were sampled for survival from age 1 through 3. From age 4 through 10, diameters of all trees taller than 4.5 feet were measured with calipers. Dominant tree heights were randomly sampled by measuring five trees per plot after the fourth and sixth years, and four trees per plot after the eighth year. Heights in the ninth and tenth years were obtained in conjunction with volume sampling.

A sample of cut tree volumes was taken after the sixth, seventh, and eighth years. After the ninth and tenth years, standing tree volumes were obtained by means of 3P sampling and a Barr and Stroud dendrometer. Ten to 15 trees were sampled in each plot. The tree volumes were used in constructing local volume tables with 1-inch d.b.h. classes for plot volume estimates. Merchantable cubic volume was figured for volume outside bark in trees $\geq$5.0 inches d.b.h. to a 4-inch top outside bark. Total volume was volume outside bark to a total height for trees $\geq$2.0 inches d.b.h.

Values presented in Results represent the average of two plots except that four plots each were used for the 12 by 12 and 16 by 18 checks. Results and discussions in this paper do not imply statistical inferences where values are presented as larger or smaller and more or less.

RESULTS

Growth Characteristics

Diameter growth of individual trees varied widely within plots. For example, on a 16 by 18 plot, where average diameter of all trees at age 10 was 10.9 inches, one tree was only 4.0 inches. Conversely, on an uncut 4 by 9 plot, where average diameter was only 5.5 inches, a dominant tree was 13.9 inches. As earlier studies have shown (Mohn and Randall 1971), it was evident by the fourth year whether a tree was going to grow rapidly.

Clusters of trees showed either above or below average diameter growth in portions of many plots. Growth differences among clusters could well reflect microsite differences.

The pattern of diameter growth was similar for the 10 largest trees per plot in all treatments and spacings. Diameter growth was most rapid during the first 4 years and gradually decreased during the last 6 years.

Height growth of dominants varied among plots but appeared unrelated to spacing or thinning treatment. After 10 years, the average height for dominant trees was 86 feet, but the range by plots was from 79 to 94 feet. Generally, plots lower in elevation and probably with better moisture relations gave the best growth rates.

Check Plots

On uncut plots, survival increased as spacing increased (fig. 3). Thus, tenth-year survival ranged from 52 percent with the closest spacing to 87 percent with the widest. In all spacings, crowding or competition took mainly the small trees. Among trees 5.0 inches in diameter and larger, nearly half of the losses were attributable to wind damage. Mortality among all tree sizes increased considerably in the ninth and tenth years for all spacings except the 16 by 18.

Average diameter also increased as spacing increased (fig. 4). After 10 years, average d.b.h. was 5.3, 7.0, 8.2, and 10.2 inches for the 4 by 9, 8 by 9, 12 by 12, and 16 by 18 spacings. Largest

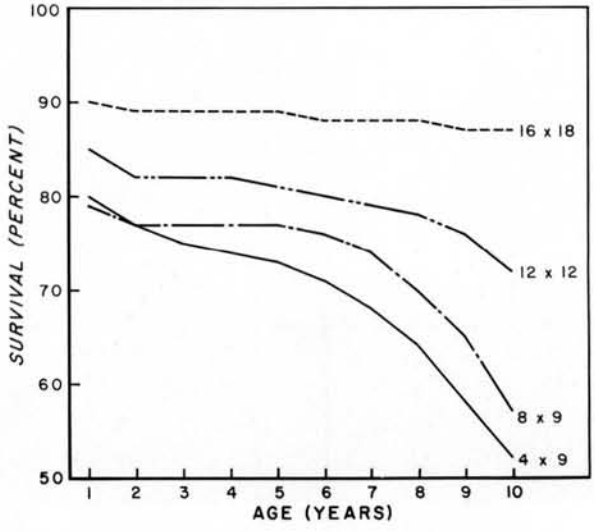

Figure 3.—*Survival of check plots.*

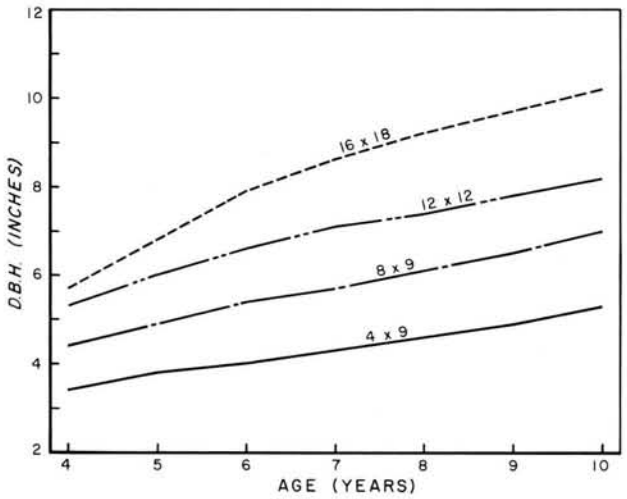

Figure 4.—*Average d.b.h. of check plots.*

diameters were in the 14-inch class (table 1). Maximum diameter growth occurred in the first 4 years for all spacings. Average annual diameter growth of all living trees apparently dropped to a minimum in the seventh year for the 4 by 9 stands and in the eighth year for the 8 by 9 and 12 by 12 stands, then increased slightly, mainly because of mortality among the smaller trees. In the 16 by 18 stands, average annual growth has decreased steadily since the fourth year.

The trend of decreasing diameter growth after the fourth year was also evident when only the 10 largest trees per plot were considered. For these trees, average annual diameter growth in the fifth through seventh year was only about one-half (12 by 12) to two-thirds (16 by 18) of their mean annual increment through age 4. During the eighth, ninth, and tenth years, their average diameter growth was only about one-third the mean annual increment through age 4.

Basal area growth was most rapid in the 4 by 9 spacing and slowest in the 16 by 18 spacing (fig. 5). Like diameter growth, annual basal area growth tended to reach a peak fairly early and then decrease. For the two closest spacings, annual basal area growth dropped during each of the last 6 years, indicating a peak before the fifth year. The 12 by 12 peaked in the fifth year; and the 16 by 18, in the seventh year.

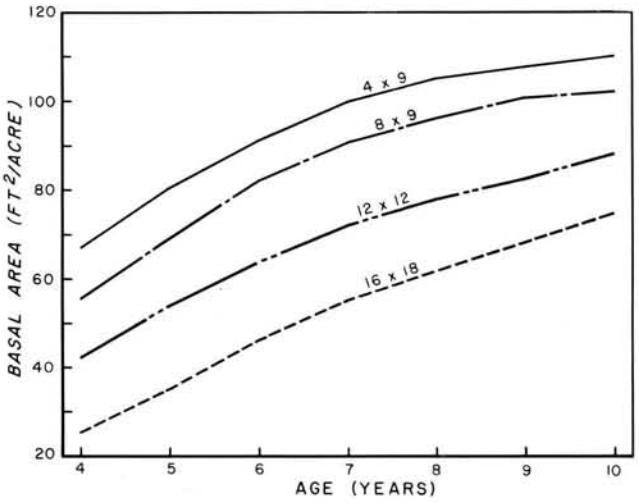

Figure 5.—*Basal area of check plots.*

Total volume at age 10 was inversely related to spacing (fig. 6). The 4 by 9 spacing with 611 trees per acre had the largest total volume, 3,544 cubic feet per acre. The 8 by 9 with half as many stems had only 100 cubic feet less volume than the 4 by 9. Total volume was lowest (2,700 cubic feet per acre) in the 16 by 18 spacing.

Maximum merchantable volume (3,033 cubic feet per acre) was achieved with the 8 by 9 spacing. There was slightly less merchantable volume in the 12 by 12, but it was concentrated on fewer, larger trees. The 4 by 9 had half again as many

Table 1.—*Diameter distribution of residual trees after 10 years by thinning treatments*

Diameter class (inches)	Check				55+/40 ft² per acre				80+/65 ft² per acre		
	4×9	8×9	12×12	16×18	4×9	8×9	12×12	16×18	4×9	8×9	12×12
	No. trees/acre										
<5.0	298	63	23	6	...	...	...	...	22	...	...
5.0–6.9	186	103	28	5	7	...	...	...	138	19	2
7.0–8.9	111	115	73	22	48	27	5	...	89	91	28
9.0–10.9	28	54	66	39	37	48	23	12	43	58	70
11.0–12.9	1	11	27	49	10	12	36	28	3	13	29
13.0–14.9	1	1	1	10	...	...	10	20	...	...	3
15.0–16.9	...	...	...	...	...	...	1	3	...	...	...
Total	625	347	218	131	102	87	75	63	295	181	132

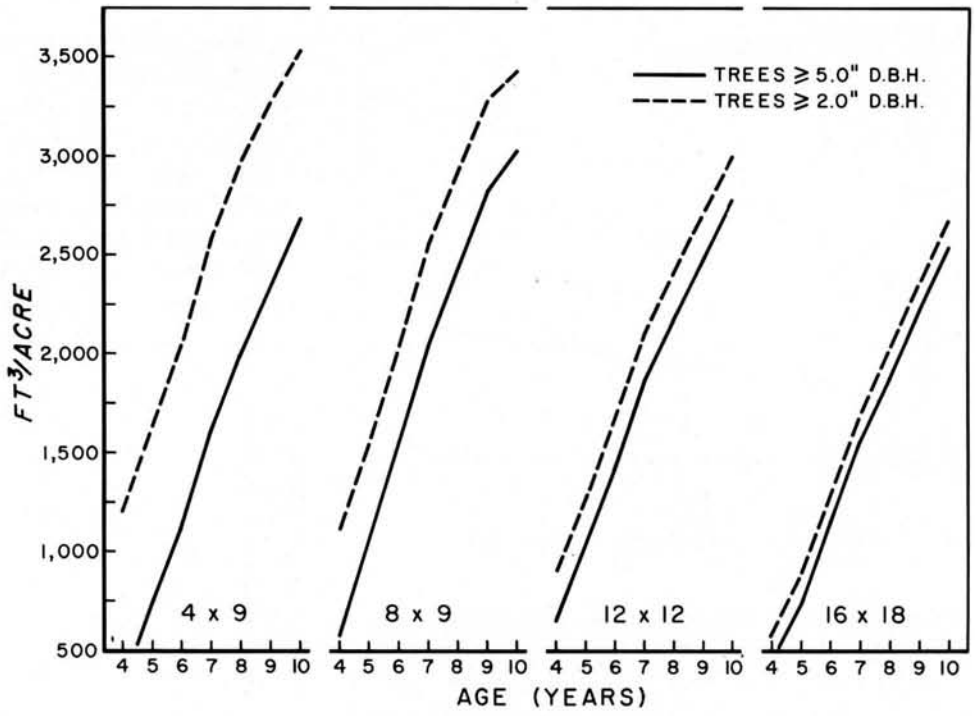

Figure 6.—*Merchantable and total cubic volume for check plots.*

merchantable trees as the 8 by 9, but average diameter was smaller, and as a result merchantable volume was about 20 percent less. The 16 by 18 plots had the lowest merchantable volume and from 70 to 200 fewer trees per acre than the other spacings. If larger threshold diameters are required for merchantability, then volumes and tree numbers are reduced (fig. 7).

Mean annual increment for total volume peaked at about 7 to 9 years for the three closest spacings; the 16 by 18 did not peak through 10 years (fig. 8). Mean annual increment for merchantable volume peaked in year 9 for the 8 by 9 spacing, but the other three spacings have not reached an obvious peak yet.

Thin 55 to 40

Thinning was done after 4, 6, and 9 years in the two closest spacings, after 6 and 8 years in the 12 by 12 spacing, and after 8 years in the 16 by 18 spacing. By age 10, spacing within all plots thinned back to 40 square feet exceeded the widest original spacing.

Just as in check plots, average diameter of 10-year residuals increased with increased spacing: 4 by 9 stands had the smallest average diameter (9.1 inches), and 16 by 18 stands had the largest (12.4 inches). Average diameters were 2 to 4 inches greater than those for trees in corresponding check plots (table 2). However, when only the 10 largest trees per plot are considered, the difference is much smaller. Only in the 12 by 12 spacing did the 10 largest trees in thinned plots achieve an average diameter of 1 inch more than that of the 10 largest trees in unthinned plots.

Merchantable volume (cut plus residual) was 52 to 552 cubic feet less in thinned plots than in corresponding check plots (table 2). Maximum production from thinned plots was 2,736 cubic feet in the 12 by 12 spacing; other spacings produced 83 to 91 percent as much. The thinned 4 by 9 plots produced the least volume of any spacing/treatment combination in the study (2,284 cubic feet).

In the first thinning, more than 90 percent of the trees cut from the two closer spacings and less than 20 percent of those cut from the two wider spacings were less than 5.0 inches in d.b.h. During the second cut, 77 percent of the trees removed from the 4 by 9 stands and 22 percent of those cut in the 8 by 9 were unmerchantable; all trees cut from the 12 by 12 were merchantable. The third cut was almost 100 percent merchantable in both 4 by 9 and 8 by 9 spacings (table 3).

Total volume (cut plus residual) in trees ≥2.0 inches in d.b.h. ranged from 2,514 cubic feet in the 16 by 18 spacing to 3,213 cubic feet in the 4 by 9 spacing. Yields were from 10 percent (two

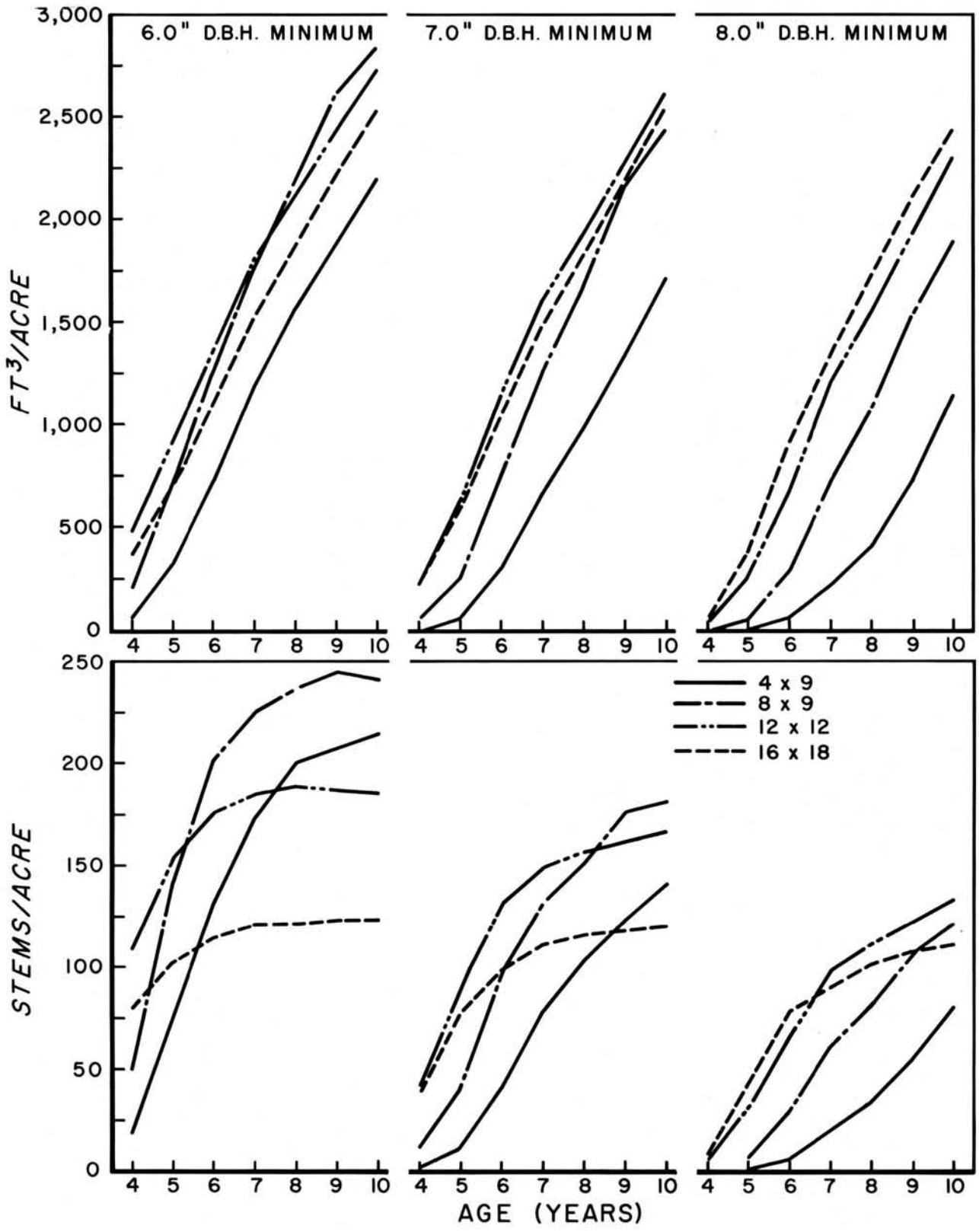

Figure 7.—*Cubic volume and density of check plots by spacing and threshold diameters (volume outside bark to 4-inch top outside bark).*

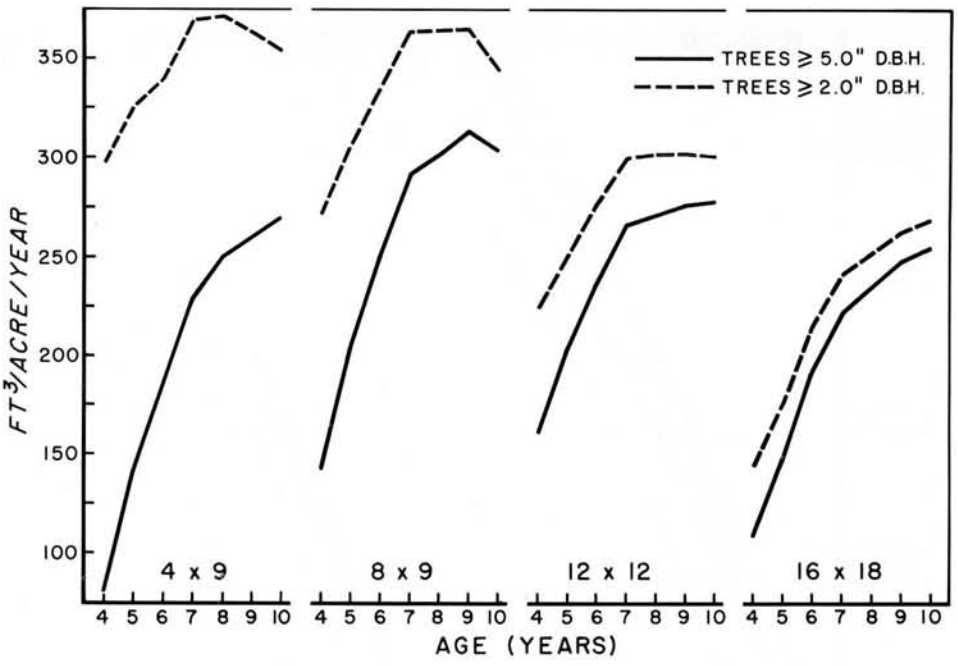

Figure 8.—*Mean annual increment of merchantable and total cubic volume for check plots.*

closest spacings) to 1 percent (12 by 12) less than yields from corresponding check plots.

Thin 80 to 65

The 4 by 9 plots were thinned after 5 and 7 years, the 8 by 9s after 6 and 8 years, and the 12 by 12s after 9 years. None of the 16 by 18 plots had exceeded 80 square feet of basal area through 9 years.

Again, diameter was directly related to initial spacing, and thinning did not increase diameter growth of uncut trees. Average diameter of 10-year residuals was smallest in the 4 by 9 plots (7.0 inches) and largest in the 12 by 12 (9.9 inches) (table 2). Although these diameters are somewhat larger than averages for trees on corresponding check plots, the mean diameters of the 10 largest trees per plot are quite similar for thinned plots and for checks (table 2).

Merchantable volume (cut plus residual) from thinned and unthinned plots differed little (table 2). The 4 by 9 was the least productive of the three spacings, and the 8 by 9 was the most productive. Both cuts in the 4 by 9 spacing and the

Table 2.—*Average diameter of all trees and of 10 largest trees per plot, and merchantable volume at age 10 by spacing/treatment combinations*

Spacing	Treatment	Plots	Average d.b.h.		Merchantable volume
			All trees	Ten largest trees	
		No.	*Inches*		*Ft³/acre*
4×9	55+/40	2	9.1	10.8	2,284
	80+/65	2	7.0	10.3	2,551
	Check	2	5.3	10.0	2,689
8×9	55+/40	2	9.7	11.1	2,481
	80+/65	2	8.7	11.4	3,058
	Check	2	7.0	11.2	3,033
12×12	55+/40	2	11.5	12.9	2,736
	80+/65	2	9.9	12.2	2,820
	Check	4	8.2	11.8	2,784
16×18	55+/40	2	12.4	13.9	2,397
	Check	4	10.2	13.1	2,549

Table 3.—*Merchantable volume and number of trees, cut and residual, in 10 years for two thinning treatments*

Spacing	First cut			Second cut			Third cut			10-yr. residual		
	<5.0 inches	≥5.0 inches	Vol.	<5.0 inches	≥5.0 inches	Vol.	<5.0 inches	≥5.0 inches	Vol.	<5.0 inches	≥5.0 inches	Vol.
	—*No. trees*—		*Ft*³	—*No. trees*—		*Ft*³	—*No. trees*—		*Ft*³	—*No. trees*—		*Ft*³
						55+/40ft²/acre						
4×9	685	3	8	123	37	262	1	71	540	...	102	1,474
8×9	245	23	64	28	99	355	1	58	604	...	87	1,458
12×12	23	98	514	...	37	452				...	75	1,770
16×18	6	47	615							...	63	1,782
						80+/65ft²/acre						
4×9	502	5	20	113	9	40				22	273	2,491
8×9	183	25	94	7	92	500				...	181	2,464
12×12	32	61	444							...	132	2,376

first cut in the 8 by 9 spacing were not commercial. Both cuts in the 12 by 12 were commercial, although 34 percent of the trees removed in the first cut were less than 5.0 inches d.b.h.

As with merchantable volume, total volume (cut plus residual) on thinned plots differed little from that on check plots. The 8 by 9 plots had the greatest yield, 3,588 cubic feet; and the 12 by 12 plots had the least, 3,070 cubic feet.

DISCUSSION

The present study on a good, but not excellent, cottonwood site indicates merchantable growth of up to 300 cubic feet, or 3.4 cords, per acre annually for the first 10 years might be anticipated. Total main-stem utilization would increase yields by 5 to 32 percent, with degree of increase in direct relation to number of trees harvested.

The forest manager should decide on the end product—pulpwood, sawtimber, or mixed products—before planting cottonwood. If pulpwood is his goal, he can choose between the 4 by 9, 8 by 9, and 12 by 12 spacings. Thinning is unnecessary and may lower production if done too early or excessively.

If all trees are to be harvested and pulped when mean annual increment peaks in the eighth or ninth year, then the 8 by 9 spacing appears best. This spacing produces about as much volume as the 4 by 9 but requires the planting and harvesting of only half as many trees. In addition, the smaller trees in the 4 by 9 stands mean a larger percentage of bark. The 12 by 12 spacing produces a total volume of 20 to 25 percent less than that of the other two spacings.

If only trees ≥5.0 inches d.b.h. are to be pulped, either the 8 by 9 or 12 by 12 spacing should be selected. In 10 years the 8 by 9 plots produced 9 percent more volume in 44 percent more trees than the 12 by 12 plots, but there were three times as many unmerchantable trees in the 8 by 9. Mean annual increment for the 12 by 12 spacing is likely to peak at about the 12th year but will probably not equal the rate of the 8 by 9. The 4 by 9 spacing is too close since at age 10 only half of the living trees may be merchantable size.

Some planters may be interested only in producing sawtimber (trees ≥13.0 inches d.b.h.). Of the spacings we tested, 16 by 18 appears best after 10 years because trees are from 2 to 5 inches larger in diameter than those at closer spacings, there are fewer trees to plant and care for, and there are fewer nonsawtimber trees to deal with. However, trees in this spacing will require artificial pruning because natural pruning will not occur soon enough to restrict limb knots to an 8-inch core.

Since diameter growth reflects crown diameter and length and since even in the widest spacing crowns were reduced to 30 to 40 percent of total height in 10 years, even the 16 by 18 spacing appears too close for maximum growth to sawtimber size. Conversely, spacings wider than 16 by 18, although maximizing diameter growth of individual trees to sawtimber size, would not allow full-site utilization for at least the first 10 years. Wider spacings would also result in poor bole quality unless an intensive program of artificial pruning were followed.

If mixed products (pulpwood plus sawtimber) are desired, timing of thinning becomes critical. To stimulate growth of residuals, thinning would likely have to occur within 3 years for the 4 by 9s, 4 years for the 8 by 9s, 6 years for the 12 by

12s, and 8 years for the 16 by 18s. Times will vary somewhat depending on tree growth, which is related to site quality and genetic make-up of planting stock. Once the critical period for thinning is passed, release seems to have little stimulus on crown enlargement and thus growth of residuals.

Thinning is further restricted by the tree size and the amount of volume that can be utilized. If only trees over 5 inches in d.b.h. will be used and if each thinning must produce a minimum of 2 cords per acre, we can draw tentative conclusions about the spacings tested. The 12 by 12 appears best because thinnings can be scheduled within a wide time range and still benefit residuals. The 4 by 9 shows little promise because a high proportion of trees never reach merchantable size and because competition restricts diameter growth of individual trees. More potential is visible in the 8 by 9s, but early thinning to favor dominants will result in lower merchantable yields than in the 12 by 12 and delaying thinnings would result in reduced growth of dominants. The 16 by 18 results in only partial site utilization and correspondingly low total yields during the first 10 years.

There is no apparent best spacing. Perhaps the best compromise of those tested is 12 by 12 feet, for it results in good pulpwood production with or without thinning, good average growth of dominants, and fair tree quality. This spacing provides enough stocking from planting one-half to one-fourth of the trees needed at closer spacings, provides flexibility for the forest manager to harvest after a pulpwood rotation with only slightly less production than the best pulpwood spacing (8 by 9), and provides for extending production into sawtimber with only a slightly longer rotation and somewhat better bole quality than the 16 by 18.

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