TB 1404 (1969) USDA TECHNICAL BULLETINS UPDATA
EFFECTS OF AGE, PLANT SPACING, AND OTHER VARIABLES ON GROWTH, YIELD, AND
WILSON, F.D., JOYNER, J.F. 1 OF 1

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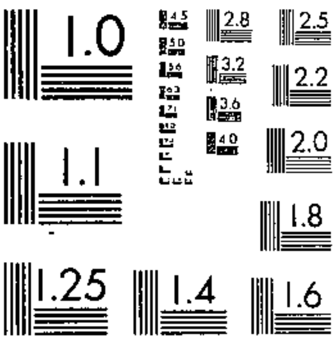

MICROCOPY RESOLUTION TEST CHART
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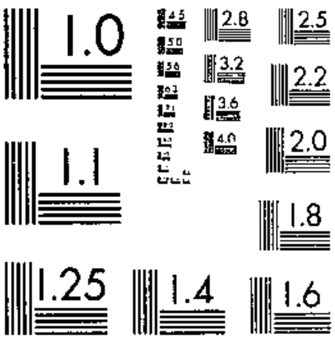

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Effects of Age, Plant Spacing, and Other Variables on Growth, Yield, and Fiber Quality of Kenaf, *Hibiscus cannabinus* L.

Technical Bulletin No. 1404

Agricultural Research Service
UNITED STATES DEPARTMENT OF AGRICULTURE

Contents

Washington, D.C. Issued July 1969

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 15 cents

Effects of Age, Plant Spacing, and Other Variables on Growth, Yield, and Fiber Quality of Kenaf, *Hibiscus cannabinus* L.[1]

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Kenaf (*Hibiscus cannabinus* L.; Malvaceae) has been grown for food and fiber for many centuries by various native peoples in the Tropics. It is presently grown on a large scale in India, and on a smaller scale in other countries, as a source of bast fiber used for twine, burlap, and other products. It has been the subject of experimental investigation in the United States, both as a source of bast fiber and of paper pulp.

Kenaf breeders have studied the relation of fiber yield to its components in attempts to predict yield without sacrificing plants. For example, Nelson and Wilson (*8*)[3] concluded that measurements of height, stem diameter, and stand will give satisfactory estimates of total yield, and perhaps of fiber yield, in early-generation testing within a given experiment.

Breeders have also studied the effects of certain variables—among them time of planting, spacing, age of plants when harvested, fiber-extraction procedures, and climatic conditions—on yield components, yield, and fiber quality.

This bulletin reports the results from an experiment designed to study the interrelations among yield components, yield, and fiber quality and the effects of age, spacing, retting method, and certain sampling procedures on yield and fiber-quality characteristics.

MATERIALS AND METHODS

We planted seed of Kenaf (*Hibiscus cannabinus* L.) variety 'Everglades 41' in Leon fine sand at an experimental farm maintained by the U.S. Department of Agriculture near Lake Worth, Palm Beach County, Fla., on May 2, 1962. Seed were planted with a Planet Jr.

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[1] Research work on which this bulletin is based was done cooperatively by the Crops Research Division and the Agricultural Engineering Research Division, Agricultural Research Service, U.S. Department of Agriculture, and the Florida Agricultural Experiment Station, Everglades Experiment Station, Belle Glade, Fla.

[2] Retired.

[3] Italic numbers in parentheses refer to Literature Cited, p. 19.

planter, setting No. 21, in rows 7 inches apart and 13 or 26 feet long. Later plants were hand-thinned to 2 inches apart in the 13-foot rows and 4 inches apart in the 26-foot rows.

Experimental design was a split-plot arranged in four randomized blocks. Individual plots were 15 rows (105 inches) wide. A light application of a 12–4–8 fertilizer was made in the row before planting the seed, and later the rows were sidedressed with nitrate of soda-potash.

Plots were sampled in the following manner: six stalks from the first row inside the border row of each plot were harvested at 15-day intervals, beginning when plants were 60 days old (July 1, 1962) and continuing until plants were 165 days old (October 13, 1962), or eight harvests in all. Harvests were considered to be the split-plot treatments in the analysis. The length of each stalk was measured in inches and then three 15-inch sections were cut from each stalk (except at first harvest, when it was possible to cut only one section from each stalk). The "basal" section was taken from 12 to 27 inches above the base of the stalk, the "middle" section was taken from 27 to 42 inches above the base, and the "top" section was taken from 12 to 27 inches below the apex. The sections were weighed to the nearest gram, diameters were measured to the nearest millimeter, and then the sections from three of the stalks were retted immediately (green-retted). The sections from the other three stalks from each plot were dried and stored, weighed to determine dry-matter content, and then held for retting until after the last harvest (dry-retted). Stem sections and retting methods were considered to be split-split plots. The fiber samples both from green- and dry-retted stalks were conditioned for at least 48 hours at 75° F. and 65 percent relative humidity and then weighed to the nearest milligram.

Fiber-quality data were obtained at the Cordage Fibers Testing Laboratory, Everglades Experiment Station, Belle Glade, Fla.: the assistance of Irene Doub, fiber technician, is gratefully acknowledged. Data obtained were tensile strength (defined as the weight required to break the fiber and calculated as the load, or force, required per unit area of the cross section of a fiber bundle 15 inches long and weighing 325 mg.) and tex (a measure of fiber fineness, defined as the weight in milligrams of a single fiber 1 meter in length, and calculated by counting the number of fibers in a bundle of fibers weighing 325 mg. then applying an appropriate formula).

Experimental data were analyzed at the Biometrical Services Laboratory, Agricultural Research Service. Individual means were compared by Duncan's multiple range test. Correlation coefficients were calculated for all pairs of traits measured. In addition, certain within-class correlation coefficients were calculated between plant height and stem diameter, plant height and fiber yield, stem diameter and fiber yield, and plant height, stem diameter, and fiber yield. Regression of fiber yield on stem diameter and on plant height at which diameter measurements were made was calculated on a within-harvest, plant spacing, and section basis in an attempt to predict fiber yields per plant and per unit area from sample yields. Also, various regression equations were generated from data on basal + middle, basal

+ top, middle + top, and basal + middle + top sections, for the purpose of comparing the relative predictability of specific equations.

RESULTS

Table 1 presents main-effect means for plant spacing, age of plants (harvest date), retting method, and stem section for yield components, fiber yield, and fiber quality (tensile strength and tex).

Effects of Spacing

Plants spaced 4 inches apart in the row had significantly larger stem diameters than those spaced 2 inches apart. However, plants spaced 2 inches apart exhibited significantly higher percent fiber (both green- and dry-weight basis) and percent dry matter than those spaced 4 inches apart. Plant spacing had no significant effect on plant height, fiber yield per sample, tensile strength, or tex.

Effects of Age of Plant

Plant height increased from 60 to 165 days of age but not at a steady rate. For example, average height increased 30 inches during July, only 8 inches during August, and 13 inches during September. Some of this variation in growth rate is attributed to variation in rainfall. The curves for daily rainfall[4] and for growth of kenaf showed some marked similarities. Stem diameter and fiber yield also increased with an increase in age but not so consistently as plant height. For example, both average stem diameter and fiber yield were slightly lower at 165 days than at 150 days. These lower values are attributed to sampling variability.

Percent fiber (green-weight basis) increased steadily up to August 30, when plants were 120 days old, and declined slightly at later harvests. Percent fiber (dry-weight basis) apparently varied randomly; at least, it was not obviously affected by the age of the plants. Percent dry matter, however, increased significantly from 75 to 90 days, then varied somewhat randomly.

Tensile strength was highest when plants were 90 days old, then declined slightly, and remained relatively constant thereafter. Tex did not vary significantly as plants grew and developed.

Effects of Retting Method

Plant heights and stem diameters were not significantly different in the samples chosen for green- and dry-retting. Percent fiber (green-weight basis) and fiber yield per sample were slightly but significantly higher from the dry-retted samples than from the green-retted samples.

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[4] Supplied by Keith Butson, Florida State Climatologist, U.S. Weather Bureau.

TABLE 1.—*Main-effect means for plant height, stem diameter, percent fiber (green- and dry-weight basis), percent dry matter, fiber yield per stem section, fiber tensile strength, and tex in kenaf* (Hibiscus cannabinus *var. 'Everglades 41'*) [1]

Main effects	Plant height	Stem diameter	Percent fiber: Green-weight basis	Percent fiber: Dry-weight basis	Dry-matter	Fiber yield	Tensile strength	Tex
	Inches	*Mm.*			*Percent*	*Grams*	*1,000 p.s.i.*	*Mg./m.*
Plant spacing:								
2-inch	71.1 a	9.4 b	7.68 a	26.76 a	29.86 a	1.202 a	48.4 a	1.948 a
4-inch	76.1 a	10.1 a	6.97 b	25.21 b	28.63 b	1.305 a	46.7 a	1.943 a
Age of plants:								
60 days (7–1)	40.4 d	5.8 e	4.70 d	-----	-----	.397 f	----	-----
75 days (7–16)	59.1 c	8.7 d	6.39 c	26.73 b	23.05 e	.805 e	49.0 ab	1.819 a
90 days (7–31)	70.3 b	9.1 cd	7.16 b	23.75 d	31.94 ab	.973 de	51.5 a	1.872 a
105 days (8–15)	72.6 b	9.9 bc	7.43 ab	26.05 bc	29.25 c	1.251 cd	46.8 b	2.064 a
120 days (8–30)	78.6 b	9.8 bc	8.05 a	27.91 a	30.02 bc	1.355 bc	47.8 ab	1.903 a
135 days (9–14)	79.7 b	8.7 d	7.44 ab	28.62 a	26.64 d	1.088 cde	46.3 b	1.796 a
150 days (9–29)	91.9 a	11.3 a	7.76 ab	24.88 cd	33.15 a	1.667 a	45.9 b	2.062 a
165 days (10–14)	96.2 a	10.8 ab	7.04 bc	23.94 d	30.66 bc	1.633 ab	45.5 b	2.102 a
Retting method:								
Green	73.5 a	9.7 a	7.09 b	-----	-----	1.180 b	----	-----
Dry	73.7 a	9.8 a	7.56 a	-----	-----	1.327 a	----	-----
Stem section:								
Top	----	6.5 c	6.82 c	24.75 c	28.05 b	.597 b	55.1 a	2.113 a
Middle	73.6	10.6 b	7.95 a	27.71 a	29.93 a	1.615 a	48.5 b	1.851 b
Basal	----	12.1 a	7.20 b	25.49 b	29.76 a	1.549 a	39.1 c	1.872 b

[1] Means within main-effect categories with letters in common are not significantly different at the 5-percent level, according to Duncan's multiple range test.

Effects of Stem Section

Stem diameter was highest in the basal section, next in the middle section, and lowest in the top section, as expected. However, percent fiber (both green- and dry-weight basis), percent dry matter, and fiber yield per sample were highest in the middle section and lowest in the top section.

Fiber extracted from the top section was significantly stronger and coarser than that from the middle section; that from the middle section was significantly stronger, but not coarser, than that from the basal section.

Interactions

The following interactions were generally nonsignificant: spacing X harvests; spacing X method of retting; spacing X stem section; spacing X harvests X stem section; spacing X retting X stem section; spacing X harvests X retting; harvests X retting X stem section; and the single third-order interaction.

Harvests X method of retting interaction was significant for percent fiber (green-weight basis); percent fiber in dry-retted stems was lowest at 75 days of age, but it was higher thereafter than percent fiber in green-retted stems. Harvests X method of retting was also significant for fiber yield per sample; the pattern was similar to that for percent fiber.

Harvests X stem section interaction was significant for stem diameter, percent fiber (green- and dry-weight basis), fiber yield, and tensile strength. Patterns for stem diameter (fig. 1, *A*) and fiber yield per sample (fig. 1, *B*) were similar. Both stem diameter and yield increased with age in the basal and middle sections, but they remained relatively constant in the top section. The response patterns for percent fiber (green-weight basis) in the basal and middle section were similar, but in the top section they were different and more variable (fig. 1, *C*). The patterns for percent fiber (dry-weight basis) were variable for all three sections, but these also were similar for basal and middle sections and different for the top section (fig. 1, *D*). The harvests response for tensile strength was different for all three stem sections (fig. 1, *E*). Tensile strength of fiber from the basal section remained relatively constant; that from the middle section varied considerably but increased consistently from 105 to 150 days of age; that from the top section was very high in early ages, but decreased consistently from 105 to 150 days. In fact, the top and middle response lines bisect each other between 135 and 150 days and again between 150 and 165 days. The harvest X stem section interaction was not significant for tex.

Method of retting X stem section interaction (table 2) was significant for percent fiber (green-weight basis). The data indicate that they were similar but different in magnitude. For example, percent fiber in the top section was almost the same whether stem samples had been green- or dry-retted, but percent fiber in the middle and basal sections was higher from dry- than from green-retted stalks.

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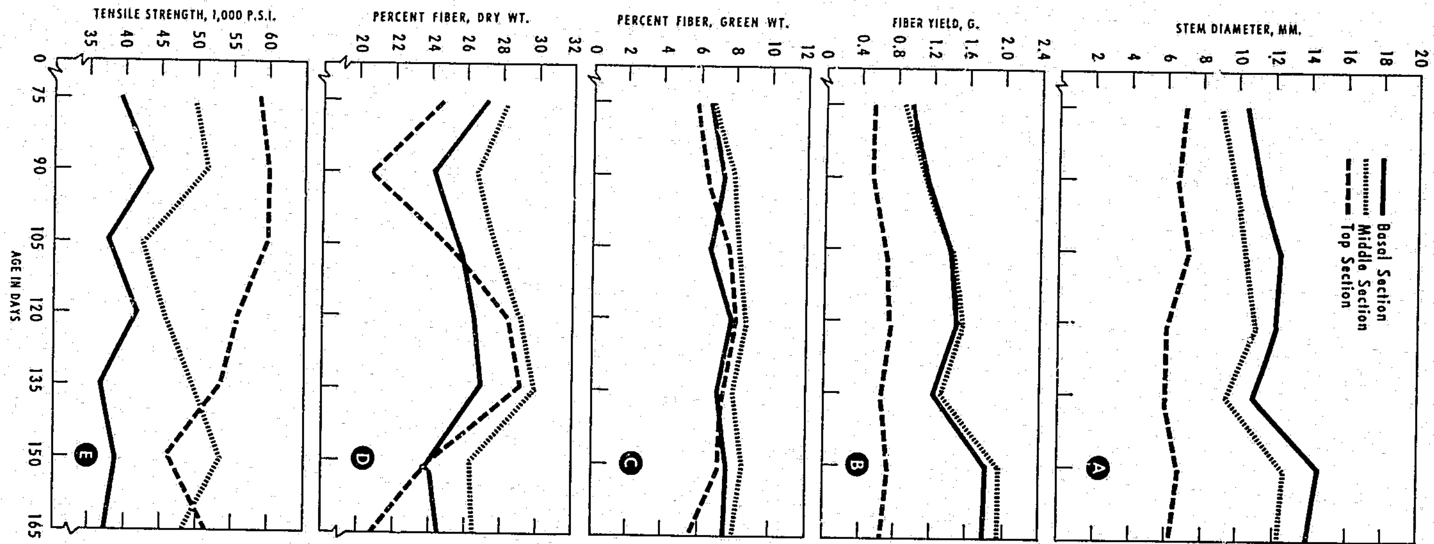

FIGURE 1.—Age of plant X stem section interaction effects in kenaf: *A*, Stem diameter; *B*, fiber yield; *C*, percent fiber (green-weight basis); *D*, percent fiber (dry-weight basis); *E*, fiber tensile strength.

TABLE 2.—*Method of retting X stem section interaction effects on percent fiber (green-weight basis)*

Method of retting	Percent fiber, green-weight basis [1]		
	Top of stem	Middle of stem	Base of stem
Green	6.74 c	7.64 b	6.89 c
Dry	6.91 c	8.26 a	7.51 b

[1] Values followed by the same letter are not significantly different at the 5-percent level, according to Duncan's multiple range test.

Correlations

Table 3 presents the combined total simple correlation coefficients for yield components, fiber yield, and fiber quality. These coefficients were calculated on an among-harvests basis; thus, they were affected by plant growth and development. However, this analysis enabled us to determine that three coefficients were large enough to give useful r^2 values—between plant height and stem diameter, plant height and fiber yield, and stem diameter and fiber yield.

Correlation coefficients (within harvests and stem sections) were calculated for all combinations of these three variables (table 4). Cor-

TABLE 3.—*Combined total simple coefficients of correlation for yield components, fiber yield, and fiber quality*

Characters correlated	Stem diameter	Percent fiber		Percent dry matter	Fiber yield	Tensile strength	Tex
		Green-weight basis	Dry-weight basis				
Plant height	0.88**	0.48**	0.17	0.67**	0.86**	−0.52**	−0.04
Stem diameter		.53**	0	.41**	.94**	−.42**	.13
Percent fiber:							
Green-weight basis			.55**	.70**	.38**	.19*	.04
Dry-weight basis				.26**	.15		
Percent dry matter					.52**		
Fiber yield						−.39**	.17
Tensile strength							−.01

*Differences significant at the 5-percent level of probability.
**Differences significant at the 1-percent level of probability.

TABLE 4.—*Simple coefficients of correlation (within harvests and stem section) between plant height and stem diameter, plant height and fiber yield, and stem diameter and fiber yield, and multiple coefficients of correlation for plant height, stem diameter, and fiber yield per stem section*

Age of plant and stem section	Plant height and stem diameter	Plant height and fiber yield	Stem diameter and fiber yield	Plant height, stem diameter, and fiber yield
75 days				
Top	0.15	0.31	0.63**	0.67**
Middle	.67**	.71**	.93**	.96**
Basal	.57**	.54**	.97**	.97**
90 days				
Top	.17	.35	.90**	.92**
Middle	.44*	.24	.89**	.91**
Basal	.27	.06	.90**	.92**
105 days				
Top	.77**	.69**	.91**	.91**
Middle	.87**	.82**	.98**	.98**
Basal	−.49*	−.38	.95**	.96**
120 days				
Top	.55**	.54**	.80**	.81**
Middle	.70**	.61**	.95**	.95**
Basal	−.10	−.01	.93**	.93**
135 days				
Top	.64**	.58**	.91**	.91**
Middle	.69**	.67**	.54**	.68**
Basal	.74**	.53**	.89**	.91**
150 days				
Top	.18	.40	.40	.52*
Middle	.64**	.65**	.97**	.97**
Basal	.51**	.53**	.89**	.89**
165 days				
Top	.36	−.10	.77**	.80**
Middle	.53**	.52**	.86**	.86**
Basal	.41*	.33	.85**	.85**

*Differences significant at the 5-percent level of probability.
**Differences significant at the 1-percent level of probability.

relations between plant height and stem diameter and plant height and fiber yield varied considerably, but correlations between stem diameter and fiber yield were more dependable and probably of high predictive value. Generally, the multiple correlation coefficients between plant height, stem diameter, and fiber yield were not enough higher than the simple coefficients between stem diameter and fiber yield to justify the extra effort involved in measuring plant height and in calculating the multiple parameter. It would seem that fiber yield per stem section can be estimated adequately by measuring stem diameter.

Another set of correlation coefficients (among harvests, within plant spacing, method of retting, and stem section) were calculated for all combinations of these three variables (table 5). Results were much the same as in the within-harvests and stem sections correlation analyses, except that the correlation between stem diameter and fiber yield was consistently lower in the top section than in the middle and basal sections.

TABLE 5.—*Simple coefficients of correlation (among harvests, within plant spacing, method of retting, and stem section), between plant height and stem diameter, plant height and fiber yield, and stem diameter and fiber yield, and multiple coefficients of correlation for plant height, stem diameter, and fiber yield per stem section*

Plant spacing, retting method, and stem section	Plant height and stem diameter	Plant height and fiber yield	Stem diameter and fiber yield	Plant height, stem diameter, and fiber yield
2-inch spacing				
Green:				
Top	0.19	0.28	0.73**	0.74**
Middle	.78**	.90**	.93**	.97**
Basal	.63*	.78**	.94**	.94**
Dry:				
Top	.22	.52	.53*	.67*
Middle	.89**	.85**	.97**	.97**
Basal	.60*	.62*	.94**	.94**
4-inch spacing				
Green:				
Top	−.32	.06	.43	.67*
Middle	.77**	.83**	.90**	.93**
Basal	.45	.46	.94**	.94**
Dry:				
Top	−.32	.36	.18	.37
Middle	.69**	.77**	.93**	.95**
Basal	.60*	.63*	.90**	.91**

*Differences significant at the 5-percent level of probability.
**Differences significant at the 1-percent level of probability.

Regressions

The linear regression of fiber yield on stem diameter and also on height at which each diameter measurement was obtained was calculated to estimate fiber yield and to compare these estimates with actual yields (within harvest, plant spacing, and stem section (table 6)).

Fiber-yield estimates based on the two regression equations were generally close to the actual fiber yield per sample. Both equations

TABLE 6.—*Estimation of fiber yield per stem section from (a) regression of yield on stem diameter and (b) regression of yield on height at which diameter was measured; and actual fiber yields*

Age of plants and stem section	Fiber yield in designated plant spacing					
	2-inch			4-inch		
	Calculated		Actual	Calculated		Actual
	(a) [1]	(b) [2]		(a) [1]	(b) [2]	
75 days	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
Top	0.534	0.659	0.429	0.751	0.659	0.510
Middle	.893	.737	.837	1.252	.866	1.037
Basal	1.149	1.157	.851	1.559	1.286	1.170
90 days						
Top	.534	.659	.455	.637	.659	.519
Middle	1.149	1.051	1.058	1.354	1.130	1.371
Basal	1.354	1.471	1.041	1.713	1.600	1.398
105 days						
Top	.637	.659	.602	.842	.659	.751
Middle	1.149	1.073	1.291	1.559	1.289	1.829
Basal	2.021	1.493	1.736	1.508	1.709	1.302
120 days						
Top	.534	.659	.697	.586	.659	.704
Middle	1.457	1.258	1.706	1.559	1.440	1.715
Basal	1.611	1.678	1.662	1.867	1.860	1.652
135 days						
Top	.381	.659	.527	.534	.659	.619
Middle	.996	1.331	1.249	1.354	1.426	1.503
Basal	1.303	1.751	1.166	1.662	1.846	1.469
150 days						
Top	.637	.659	.658	.637	.659	.707
Middle	1.764	1.661	2.116	1.867	1.779	2.381
Basal	2.123	2.081	2.012	2.328	2.199	2.134
165 days						
Top	.586	.659	.595	.432	.659	.586
Middle	1.918	1.779	2.395	1.662	1.902	2.130
Basal	2.174	2.199	2.163	2.021	2.322	1.934

[1] ($\hat{Y}=-0.747+0.205X$), where $\hat{Y}$=fiber yield per sample and X=stem diameter.
[2] ($\hat{Y}=0.113+0.028X$), where $\hat{Y}$=fiber yield per sample and X=distance below the tip of the plant at which stem diameter was measured.

tended to overestimate fiber yield of the basal sample, because the actual yield was lower in the basal than in the middle section at 120 days and thereafter in plants spaced 2 inches apart and at 105 days and thereafter in plants spaced 4 inches apart.

We used the regression of fiber yield per section on distance (inches) below the tip of the plant at which stem diameter was measured ($\hat{Y}=0.113+0.028X$) to estimate the fiber yield: (1) per plant (table 7)

TABLE 7.—*Estimation of total yield of fiber per plant from regression of fiber yield per stem section on height at which stem diameter was measured*

Age of plants, days	Fiber yield per plant in designated plant spacing	
	2-inch	4-inch
	Grams	*Grams*
75	3.77	4.39
90	5.27	6.04
105	5.40	6.66
120	6.35	7.43
135	6.74	7.27
150	8.86	9.93
165	9.93	10.31
Average	6.62	7.43

to obtain relative increases in yield with increases in age and yield per-acre estimates; and (2) per basal, lower middle, upper middle, and top quarter sections of the stem (table 8) (for comparison with previous reports in the literature) to obtain proportions of the fiber found in various parts of the plant.

We were also interested in the relative predictability of various regression equations generated by the use of only two of the three diameter measurements. For example, would it have been possible to predict yield per section as accurately if data had been obtained from only basal + middle, basal + top, or middle + top rather than from all three regions of the plant? Calculated average fiber yield per stem sample for the four possible regression equations and actual average fiber yield per stem sample are presented in table 9.

TABLE 8.—*Estimation of average fiber yield per stem section; and corresponding percentages of the total yield*

Stem section	Fiber yield in designated plant spacing		Percent of total fiber yield in designated plant spacing	
	2-inch	4-inch	2-inch	4-inch
	Grams	*Grams*	*Percent*	*Percent*
Top	0.59	0.67	8.9	9.0
Upper middle	1.24	1.38	18.8	18.6
Lower middle	1.87	2.11	28.2	28.4
Basal	2.92	3.27	44.1	44.0
Total	6.62	7.43	100.0	100.0

TABLE 9.—*Estimation of fiber yield per stem section by the use of 4 regression equations: and deviations from actual average fiber yields*

Regression equation and stem section [1]	Calculated average fiber yield	Deviation from actual average fiber yield [2]
Basal + middle	*Grams*	*Grams*
($\hat{Y}=0.401+0.023X$):		
Top	0.850	0.253
Middle	1.411	−.204
Basal	1.756	.207
Basal + top		
($\hat{Y}=0.093+0.025X$):		
Top	.581	−.016
Middle	1.191	−.424
Basal	1.566	.017
Middle + top		
($\hat{Y}=-0.161+0.040X$):		
Top	.619	.022
Middle	1.595	−.020
Basal	2.195	.646
Basal + middle + top		
($\hat{Y}=0.113+0.028X$):		
Top	.659	.062
Middle	1.342	−.273
Basal	1.762	.213

[1] X, distance below the tip of the plant at which diameter was measured; $\hat{Y}$, fiber yield per sample.
[2] Actual average fiber yield: Top, 0.597; middle, 1.615; basal, 1.549.

As might be expected, the regression equation middle + top more accurately predicted actual yield of the middle and top sections than of the basal section; likewise, the equation basal + top more accurately predicted actual yield of the basal and top sections than of the middle section. The basal + middle equation and the basal + middle + top equation, however, did not perform as expected, because the actual fiber yield of the middle section was higher than that of the basal section.

DISCUSSION

Previous studies of the relation of row and plant spacing to fiber yield and quality have yielded various results. Generally, however, more closely spaced plants have yielded more fiber per unit area (*4, 9*). Our study of skip-row vs. uniform-row planting (*7*) showed that the skip-row spacing 7–14–7 inches resulted in higher fiber yields than the uniform 7-inch-row spacing on sandy soil but not on peat soil. Results of variety tests suggested that kenaf compensates in yield for differences in stand to a significant degree. Wide differences in stand above 4.5 stalks per square foot on Everglades peat soil did not affect plot fiber yields greatly. Stands below this figure, however, were highly correlated with yields ($r=0.95$).

In the experiment reported herein (plants grown in 7-inch rows on sandy soil), plants spaced 2 inches apart in the row had a stand approximating 12 plants per square foot and those spaced 4 inches apart had a stand approximating six plants per square foot. Nevertheless, the more widely spaced plants did not compensate in individual plant yield enough to counteract the deficiency in stand. At 120 days, plants spaced 2 inches apart gave an estimated yield of 6.35 g. of fiber per plant (table 7), or a projected yield of 6,247 pounds per acre, and plants spaced 4 inches apart gave an estimated yield of 7.43 g. of fiber per plant, or a projected yield of 3,655 pounds per acre.

The plants spaced 4 inches apart in the row were larger than those spaced 2 inches apart, as expected, but had a lower fiber percentage. The lower fiber percentage in plants with large stalks is a direct result of the higher wood/bark ratio in these plants. This is another reason why close spacing and plants with stems of small diameter are more desirable.

Age in relation to yield and yield components has been studied by several workers. Crane and coworkers (*4*) and Ergle and coworkers (*5*) found that fiber yield and percent fiber (green-weight basis) and percent dry matter increased with age but that percent fiber (dry-weight basis) fluctuated more or less at random or remained relatively stable. These changes are presumably consequences of the growth, development, and maturing of the plants under a decreasing daylight regime.

Considerable disagreement exists as to the best time to harvest kenaf for fiber. Two concepts are prevalent. One is that kenaf should be harvested in a given number of days after planting (usual recommendation is 90 to 120 days). The other is that kenaf should be harvested when it reaches the proper physiological age, i.e., when it begins to flower. Data from the present experiment bear directly on this problem.

Ninety-day-old plants, still in the vegetative stage, gave a calculated fiber yield of 5.27 grams per plant; those 135 days old, at an early-flowering stage, gave an estimated yield of 6.74 grams per plant; and those 165 days old, in a flowering and green-capsule stage, gave an estimated yield of 9.93 grams per plant.

Our data suggest that tensile strength was significantly greater when plants were 90 days old than when plants were 135, 150, or 165 days old. In an earlier study,[5] fiber of comparable strength and fineness was produced at every age from 100 to 230 days in kenaf planted March 1960. Tensile strength in 80- and 90-day-old material in our test was significantly lower than that in older material in the earlier study. This finding again emphasizes that chronological age is not a good criterion to use in deciding when to harvest kenaf. Plants in the 1960 study were 90 days old on June 18; they had been subjected during their growing period to a gradual increase in the photoperiod. Plants in the present study, however, were not 90 days old until July 31, 1962; part of their growth had come during a decrease in the photoperiod.

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[5] Joyner and Wilson, unpublished.

The higher fiber percentage and fiber yield from dry-retted samples than from the green-retted samples is probably an artifact. That is, more bark, gums, and other similar substances adhered to the dry-retted fiber than to the green-retted fiber. This situation is probably analogous to that in comparing retted with decorticated fiber. More material adheres to the decorticated fiber and causes it to weigh more than the cleaner fiber; hence, a spurious increase in percent fiber and in fiber yield.

The basic growth pattern of the kenaf plant served as a model for stem-sampling techniques. The basal and middle samples were always selected at the same height above the ground (basal, 12 to 27 inches; middle, 27 to 42 inches) and should thus reflect primarily the influence of continued secondary growth and fiber deposition on fiber yield, yield components, and quality. The top section was always sampled the same distance from the growing point (12 to 27 inches below the apex) and should thus reflect mostly the influence of primary growth on yield and quality characteristics. Theoretically, yield per stem sample is expected to increase significantly in the basal and middle section, but to remain relatively constant in the top section, with increase in age. In other words, the physiological age of the middle and basal sections should change significantly but that of the top section should not vary much from the first to the last harvest, providing the plants are growing actively during this time.

The age of plant X stem section interaction curves show that stem diameter (fig. 1, *A*) and fiber yield (fig. 1, *B*) increased generally in basal and middle sections but remained relatively constant in the top section.

Logically fiber yield of the basal section is expected to be highest, because the basal section is oldest and has therefore undergone more secondary growth. However, figure 1, *B*, shows that fiber yield in the basal section was slightly higher than that in the middle section at 75 days, was the same at 90 days, but was slightly but not significantly lower at each subsequent age.

Several explanations may account for this result. One is that the small yield in the basal section is spurious in the sense that a smaller proportion of the potential amount of fiber was recovered because the bark adhered more tightly to the stem. Another is that the rate of fiber deposition steadily decreased as the plant matured. Secondary growth (cambial activity) in kenaf stems ceases first at the base and proceeds upward. However, secondary growth (increase in stem diameter) continued at about the same rate in both basal and middle sections in our plants (fig. 1). A third explanation is that, as secondary growth proceeds, proportionately more wood than fiber is laid down, so that diameter increases at a faster rate than fiber content.

Tensile strength of fiber from the top section was generally higher than that from other sections, which suggests a fundamental difference in the nature of the primary and secondary fibers. Arno and Borschtshowa (*1*) found that the primary fibers from the outer bast cylinder (which arise from the terminal meristem) can be distinguished from the secondary fibers from the inner bast cylinder (which arise from cambial activity). They described the primary fibers as being more tightly packed together, glossier, and more flexible than the secondary fibers. They also showed that the primary fibers were stronger than the secondary fibers and that all the fibers from a thin stalk were slightly stronger than the fibers from a thick stalk. They found the proportion of primary to secondary fibers to average about 35 to 65 percent in the whole stalk. Unfortunately, we had overlooked this distinction when we were processing the samples from our study, but their findings agree with our observations and explain why tensile strength of fiber from the top section was highest.

One complication in our test was that tensile strength of fiber from the top section did not remain the highest. It was significantly higher in the second, third, fourth, and fifth harvests but not in the sixth, seventh, and eighth harvests (fig. 1, *E*). This result may reflect a subtle effect of maturation of the plant even on the fiber in the top section. It would be hard to explain on the basis of Arno and Borschtshowa's findings, since they worked with plants at the "technical stage of maturity" (browning of the lower capsules)—older than any of the plants with which we worked. On the other hand, this result may reflect a difference in fiber properties caused by variation in retting procedures, since tensile strength is based on fiber from green-retted stalks only. One fact, however, suggests that retting methods were satisfactory. This fact is that tensile strength of the fiber from the basal section did not differ significantly from the second to the eighth harvest. This finding suggests that the gradual decrease in strength in fiber from the top section and its gradual increase from the middle section represent real trends rather than merely the effects of sampling variation.

Other studies of the correlation between fiber yield and yield components in kenaf agree reasonably well with ours, even though calculated in different seasons and from different localities (table 10).

TABLE 10.—*Comparison of correlation coefficients for fiber yield and yield-component variables in kenaf, grown at 4 locations*

Characters correlated	Total correlation coefficients			
	Dacca, East Pakistan 1950 [1]	Gainesville, Fla., 1965 [2]	Belle Glade, Fla., 1965 [2]	Lake Worth, Fla., 1962 [3]
Plant height and stem diameter	0.64**	0.83**	0.74**	0.88**
Plant height and fiber yield	.80**	.42*	.84**	.86**
Stem diameter and fiber yield	.65**	.47*	.52**	.94**
Plant height, stem diameter, and fiber yield	.81**	.83+**	.84+**	.94+**

[1] Chaudhuri and Islam (*2*).
[2] Sam-Ell Julcofy (footnote 6, p. 16).
[3] This bulletin.
*Differences significant at the 5-percent level of probability.
**Differences significant at the 1-percent level of probability.

Chaudhuri and Islam (*2*), working with a Cuban variety of kenaf in Pakistan, found the highest correlation between plant height and fiber yield per plant; but they also found highly significant positive correlations between plant height and stem diameter and between stem diameter and fiber yield. Sam-Ell Julcofy,[6] working with six varieties of kenaf at two locations in Florida, found the highest correlation between plant height and stem diameter (measured 12 inches above the ground) at Gainesville but the highest correlation between plant height and fiber yield at Belle Glade. In the present study, the highest total correlation (over harvests, plant spacing, stem section, and method of retting) were between stem diameter and fiber yield per stem section. In all three studies, the multiple correlation coefficients between plant height, stem diameter, and fiber yield were high (0.81–0.94+) and thus were of high predictive value.

Within-class correlation coefficients in our study (within harvests and stem sections; among harvests, within plant spacing, method of retting, and stem sections) between plant height and fiber yield and between plant height and stem diameter fluctuated considerably for all three stem sections. The correlation between stem diameter and fiber yield, however, fluctuated in the top section but was remarkably consistent and high for the middle and basal sections. The within-harvest multiple correlation coefficients between plant height, stem diameter, and fiber yield were high both in the basal and middle sections at every age from 75 to 165 days. These data suggest that measurements of plant height and stem diameter at an early age would help to make reasonably accurate predictions of yield at a later age.

Our overestimation of fiber yield in the basal section and underestimation of it in the middle section are direct consequences of the linear regression model used. A quadratic regression model may have been better for purposes of estimation. However, the analysis of variance indicated that fiber yields were not significantly different in the basal and middle stem sections, even though yields were consistently higher in the middle section. For this reason, we used the linear model to estimate total yield per plant and per quarter section of the plant.

We calculated fiber yield per quarter section of plant to compare directly with previous similar calculations. Gangstad and coworkers (*6*) found the following percentages of fiber in top, upper middle, lower middle, and basal quarter sections of the "Salvadorian" variety of kenaf: 5.7, 17.7, 32.8, and 43.8, respectively. Crandall (*3*) reported yields in grams per "usable" foot for several varieties of kenaf grown at two locations, Guatemala and Sudan. The observed range of percentages of total fiber yield in quarter sections of the plant (based on our calculations from Crandall's data) were as follows: top, 7.9 to 14.2; upper middle, 16.8 to 21.4; lower middle, 28.6 to 31.9; base, 35.8 to 45.5. Crandall's data indicated not only varietal differences in proportions of fiber in the four quarter sections of the plant but also marked environmental influences on a single variety. Unfortunately, his data are based on plants grown in unreplicated plots.

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[6] SAM-ELL, JULCOFY. PERFORMANCE OF BAST-FIBER VARIETIES IN NORTH AND SOUTH FLORIDA. 1966. [Unpublished master's thesis. Copy on file Dept. Agron., Univ. Fla., Gainesville.]

Our calculations for "Everglades 41" (table 8) fall in or near the range of percentages for each section of the plant stems obtained by Crandall. Our estimates were higher for the top section, lower for the lower middle section, but essentially the same for the upper middle and basal sections as those of Gangstad and coworkers (*6*).

These calculations have considerable practical value because part of the plant is sacrificed in mechanical harvesting operations. The plants are usually topped by a saw on the harvester to exclude the leaves from the ribboning, or decorticating, operation. Topping does not result in a great loss of fiber, according to present and previous calculations, because the top quarter section of the plant contains less than 15 percent of the total fiber in the plant. However, mechanical harvesters also leave a stubble; the height varies according to the type of harvester used. A long stubble would result in the loss of considerable amounts of fiber.

The data from the experiment reported herein illustrate this principle. Average plant height at 165 days of age was 96 inches. The harvester developed by the U.S. Department of Agriculture group at the Everglades Experiment Station was designed to handle stalks of 8 to 9 feet (*10*), but the topping saw would probably remove the upper 12 to 18 inches of the plant to exclude leaves from the ribboning operation. Removal of the upper 15 inches of the plant, according to our regression equation, would result in the loss of 0.32 grams of fiber. About the same amount of fiber would be lost (0.38 grams) if the harvester left a 3-inch stubble. The net amount of fiber per plant left in the field would be 0.70 grams, or about 7 percent of the total amount. To illustrate the effects of further growth on fiber yield, we calculated the total fiber per plant, using the same regression equation, from a hypothetical plant 12 feet tall. Total fiber yield would be 21.94 grams. Three feet would be cut off by the topping saw, which would result in the loss of 1.55 grams of fiber. The amount of fiber lost in a 3-inch stubble would be 0.80 grams. Total fiber loss would be 10.7 percent of the calculated fiber yield per plant. The net fiber yield (19.59 grams) would still be significantly higher than that from the plant that had grown only 8 feet tall (9.23 grams). This hypothetical result illustrates the importance of continued secondary growth on the amount of fiber in the stalk.

This principle may be illustrated further by considering some actual fiber yields. For example, the fiber yield per middle section was 0.94 grams in 75-day-old plants but had increased to 2.26 grams in 165-day-old plants. The calculated average fiber yield per inch of stalk was 0.06 grams in plants 75 days old but 0.15 grams in plants 165 days old, or 2½ times greater.

Data presented in table 9 suggest that two regression equations, each based on two measurements, predicted yield per stem section better than the one equation based on three measurements (basal + middle + top). For example, the regression equation basal + top proved to be a good estimator of actual yield in the basal and top sections. Likewise, the equation middle + top was a good estimator of actual yield in the middle and top sections. If these two are combined, the estimated yield of the top section can be taken from either equation (0.581 or 0.619, compared with actual 0.597), the estimated yield of the middle section can be taken from the equation middle + top (1.595 compared with actual 1.615), and the estimated yield of the basal section can be taken from the equation basal + top (1.566 compared with actual 1.549).

SUMMARY

Stalks of the kenaf variety "Everglades 41" were harvested every 15 days (from plants 60 to 165 days old) from plots in which plants were spaced 2 and 4 inches apart. Three 15-inch samples designated "basal," "middle," and "top" were cut from each stalk and used for determinations of fiber yield, percent fiber, and dry-matter content, fiber-quality characteristics, and for the effects of two methods of retting.

Differences in plant spacing had no significant effect on height, fiber yield per stem sample, or fiber quality. Plants spaced 2 inches apart had smaller stem diameters but significantly higher fiber and dry-matter percentages than those spaced 4 inches apart. Height, stem diameter, and fiber yield increased with age as expected. Percent fiber (green-weight basis) increased only up to 120 days. Percent fiber (dry-weight basis) varied slightly, apparently at random. Percent dry matter increased up to 90 days of age, then varied randomly. Fiber quality was not much affected by increase in age. Percent fiber (green-weight basis) and fiber yield were slightly higher from dry-retted than from green-retted stem samples.

Stem diameter was lowest in the top section and highest in the basal section, as expected, but percent fiber and fiber yield were highest in the middle section. Tensile strength and tex were highest in the top section. Certain interaction effects were significant. Possible reasons for these effects are discussed.

Combined correlation coefficients for all fiber-yield, yield-component, and fiber-quality characteristics revealed some correlations of possible use in predicting fiber yields from standing plants, i.e.: between plant height and fiber yield and stem diameter and fiber yield. Correlation coefficients (within harvests and stem section) were calculated between plant height and fiber yield, stem diameter and fiber yield, and plant height, stem diameter, and fiber yield. Coefficients between stem diameter and fiber yield and height, diameter, and fiber yield were uniformly high for middle and basal section at all ages from 75 to 165 days of age. Another set of coefficients (among harvests, within plant spacing, method of retting, and stem section) yielded similar results.

Estimates of fiber yield per stem section, calculated from the linear regression of fiber yield on stem diameter and on height at which diameter was measured, were compared with actual fiber yield per stem section. Estimated yields compared well with actual yields, except that the regression equations used consistently overestimated fiber yield from the basal section and underestimated it from the middle section. Reasons for this result are discussed.

Estimates of total fiber yield per plant were made from regression of fiber yield on height at which stem diameters were measured. Fiber

yield per plant was lower at every age in plants spaced 2 inches apart than in those spaced 4 inches apart. However, estimated yield of fiber per acre was high from plants spaced 2 inches apart.

Estimated amounts of fiber in each quarter section of the plant compared favorably with similar data in the literature. Percentages were as follows: basal, 44.1; lower middle, 28.3; upper middle, 18.7; top, 9.0.

We compared the relative agreement of estimated fiber yields calculated from various regression equations with actual yield per stem sample. Yields calculated from regression equations based upon data from only two stem sections did not agree well with actual yields of the third section. Yields calculated from regression equations based upon data from all three sections did not agree too well with actual yields of basal and middle sections, because of the unexpectedly higher yields of the middle section. Yields estimated from a combination of basal + top and middle + top regression equations agreed most closely with actual yields of all three sections.

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