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STRUCTURE, DETERMINED BY X RAY, AND STRENGTH OF COTTON FIBER
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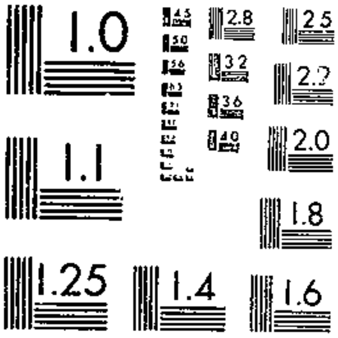
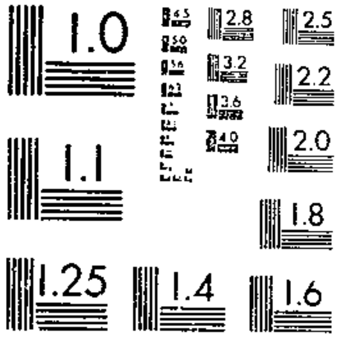


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



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NATIONAL BUREAU OF STANDARDS-1963-A

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Structure, Determined by X-Ray, and Strength of Cotton Fiber [1]

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CONTENTS

THE position of American cotton on the domestic and foreign markets depends among other factors on its quality, the maintenance or improvement of which requires rapid and accurate methods of measuring its properties. Increased competition with synthetic fibers and with foreign cottons and other natural fibers calls for new methods for measuring properties not heretofore considered. The X-ray method may be substituted for strength techniques where field damage has occurred, since in such samples it is an excellent means of (1) selecting good spinning cottons not readily identifiable as such by other fiber properties; (2) differentiating unusual varieties or strains or environmental conditions where the usual strength-structure relations may not hold; and (3) measuring relatively rapidly genetic differences affecting tensile strengths. The results of the present study on the development of the X-ray method may be summarized as follows.

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[3] Employed jointly by the North Carolina State College of Agriculture and the United States Department of Agriculture.
[4] Deceased.
[5] The authors wish to acknowledge the assistance of Mrs. Bula Carlson Ringwalt and Mrs. Mary Dooley Miller, of this Division, for making certain of the X-ray and strength measurements.

SUMMARY AND CONCLUSIONS

In comparing cotton samples for selection in breeding, the X-ray method supplements rather than replaces strength methods. Where field damage has occurred the X-ray angles may be more reliable indices of the genetic characteristics or potential fiber strengths than the Pressley values or the Chandler bundle strengths. The X-ray technique serves also as a research tool in determining reasons for differences in strength and other properties and in comparing natural and synthetic fibers.

Thus far the X-ray measurements have not been so closely correlated with yarn strengths as with fiber strengths, for two main reasons: (1) The X-ray angles are not changed materially by biological decay until after the fiber strength is completely destroyed, but the yarn strengths are affected by biological decay in much the same way. (2) The structure-strength relationship may be different for the various species of cotton and even for different varieties within a species; sea-island and American-Egyptian, for example, are stronger for a given X-ray angle than American upland varieties, and among upland strains, Wilds may be stronger than Stoneville 5 for a given cell-wall structure. In general, environmental effects within a variety do not change the structure-strength relationship.

In the studies of yarn strengths, fiber length and strength were found to be more important for 22s yarn, whereas fineness becomes progressively more important at the higher counts and at 60s may overshadow fiber strength.

Water stress, as measured by the degree of wilting of the plant, is the most important factor in the environmental effects on fiber properties. As the stress becomes greater the cellulose is deposited with a smaller angle between the long axis of the cellulose crystallites and that of the fiber, and correspondingly there is greater tensile strength. The stress may also affect the quantity of cellulose deposited, thus changing the fineness (weight per unit length) of the fiber. It may also affect fiber length; however, the fiber elongates to full length before secondary deposition takes place, thus making it possible for its length and strength to be affected independently by environment. If they are affected similarly, there is a tendency for compensation, i. e., the shorter the fiber the greater the strength.

Weather conditions that promote the growth of stronger cottons usually cause a lower yield and shorter staple, thus reducing the returns to the grower. It is logical, therefore, to expect improvement in strength of cotton through breeding rather than by specialized growing conditions.

The characteristic fiber structure (indicated by the X-ray angle) of a well-bred variety or strain of cotton tends to be genetically constant unless varied by selection. When two widely different strains or varieties are crossed, the X-ray angles of the F_1 generation tend to be equal to the average of the two parents; however, it may be equal to the parent having the smaller X-ray angle. The F_2 and succeeding progenies tend to segregate, and the extremes of X-ray angles among the progenies may be greater than that of the two parents. Selections from such a cross may remain stable or segregate further.

It may be concluded that the X-ray measurement is a valuable tool in cotton-breeding and general fiber research.

EXPERIMENTAL BACKGROUND OF X-RAY METHOD

By Earl E. Berkley and Orville C. Woodyard[6]

Various properties of cotton fibers have been studied in the joint program of the United States Department of Agriculture and the State agricultural experiment stations for the improvement of American cottons. Among these properties has been the relation between structure of fiber as shown by X-ray diffraction patterns and the fiber strength and spinning quality. It is not the purpose of this discussion to attempt any detailed explanation of fiber structure, but merely to point out that, complex and uncertain as it may appear, the average or general structure is closely related to the various physical properties of the fibers.

Previous Investigations

Investigators have known for some time that the orientation of the fibrils, with respect to the long axis of the cotton fiber, varies from one lot of fibers to another and from one position to another in a given fiber. If orientation measurements on individual fibers are desired, microscopic methods are usually preferred. Morey (*21*)[7] reported a method for measuring orientation by means of the dichroism of fluorescent dyes that are absorbed by the fibers. He later extended this method to the measurement of the average value for a large number of fibers at one time (*22*).

X-ray diffraction technique offers a rapid and practical means of determining the fiber structure of cottons by using bundles containing several thousand fibers each. A review of the literature on X-ray studies of cellulose has been given by Sisson (*25*, *26*, *29*). Clark, Pickett, and Farr (*9*) recognized the use of this method to compare different samples of cotton, and Sisson and Clark (*30*) worked out a method for comparing samples of raw cotton. Further refinements were reported by Sisson (*27*, *28*) and by Berkley and Woodyard (*6*). This section of this bulletin summarizes the development of the technique that has become one of the standard procedures for describing the relation of physical properties of cotton fibers to heredity and environment.

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[6] The authors are indebted to Carl M. Conrad, for many helpful suggestions during the progress of this work, and to John F. Barghousen, formerly with the Cotton Branch, Production and Marketing Administration, for help in designing and constructing the apparatus illustrated in figures 3, 21, and 25.

[7] Italic numbers in parentheses refer to Literature Cited, p. 62.

Fundamentals of X-Ray Method

In considering all the experimental data to be reported here, it should be remembered that the microphotometer readings are in arbitrary units that are directly proportional to $1-T$, where T is the relative transmission. If it is desired to convert the microphotometer readings to standard units, it can be done by using the information that the zero transmission reading is 255 and that for a transmission of 0.439 the reading is 90 (the standard filter setting). Standard procedure in measurements by the X-ray method is given in the last part of this report (pp. 51 to 61).

VARIATIONS IN RECORDED X-RAY PATTERNS

If diffraction patterns of three samples of cotton having different physical properties are prepared and the photographic blackening of the circle containing the arcs from the 002 plane is plotted against the angular distance around the pattern, the curves shown in figure 1, *A*, may result. The heights, widths, and areas are seen to be different for each curve. These curves are related to one or more physical properties of the cotton fibers, and the problem is to discover that relationship.

Assuming a bundle of parallel fibers held in a fixed position with reference to the X-ray beam, the shape and the size of the curve (fig. 1, *A*) are representative of the preferred direction of orientation of the cellulose crystallites in the cylindrical fibers of each sample represented. The patterns are influenced also by distribution of crystallites about preferred direction, X-ray absorption coefficient of fibers, thickness of bundle of fibers, density of bundle, tension on bundle, intensity of X radiation, length of exposure, sensitivity of film, conditions of developing, noncrystalline part of fiber, and probably a number of other factors.

Since it is obviously difficult, if not impossible, to eliminate every variable except that of cellulose orientation, so that the angle between the cellulose strands and the long axis of the fiber could be obtained directly from the dimensions of the curves, it was necessary to establish an arbitrary measure of the curves. In establishing such a measure a great number of what seemed to be the most logical procedures were investigated to determine closeness of relationship with fiber tensile strength, reproducibility, speed and facility of operation, and other technical requirements. Matano (*18*) and Go and Kubo (*11*) attempted the solution of this problem, but failed to develop a serviceable method for the large numbers of curves required in routine measurements.

In the work reported here the bundle size, tension, film characteristics, and developing processes were all held as constant as possible. This left a group of curves still having different heights, widths, and areas with variations that may be assumed to be due only to differences in cellulose orientation, distribution about the direction of orientation, and degree of exposure.

Almost at the outset it appeared that it was not practicable to adjust the degree of exposure for varying orientation to give curves having either areas or heights or widths sufficiently constant for using the other measurement in comparing curves. Theoretically, the most logical procedure would be to adjust the curves to a constant area, which would represent total X radiation. This meant, in terms of the plotted curves, making the areas the same under all the curves.

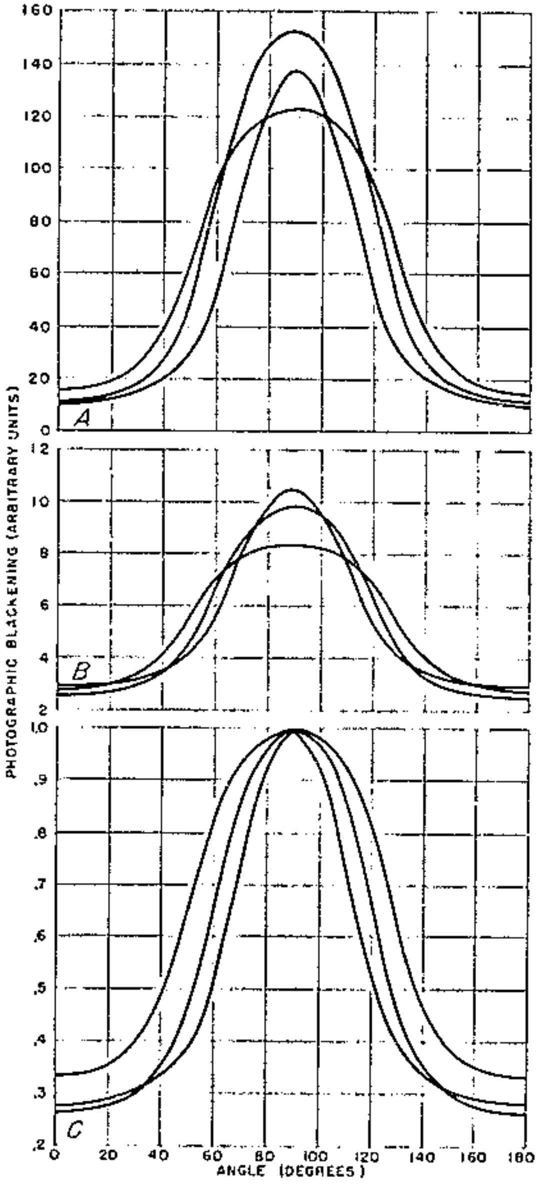

FIGURE 1.—Photographic blackening of the arc from the 002 plane from each of three patterns plotted against the angular rotation of the pattern: *A*, As measured; *B*, adjusted so that the area under each curve is the same; *C*, adjusted to the same maximum height.

This produced sets of curves similar to those shown in figure 1, *B*, which are from the same photometer readings as those in figure 1, *A*, after being adjusted to the same area. It was not practical to measure the areas of the large number of curves required for a routine method.

What proved to be a practical measure of the curves was to keep the heights fixed (i. e., a standard degree of radiation at a chosen point) and to measure the variations in widths of curves. This method would produce a set of curves similar to the examples shown in figure 1, *C*. These are the same curves as those shown in figure 1, *A* and *B*, after being adjusted to the same maximum height.

Preliminary tests showed that the angular distance from the position of maximum blackening on the ordinate to the position of 40 percent of the maximum ordinate gave a sensitive and reliable measure of curve width. Although the choice of the 40-percent angle instead of one larger or smaller is somewhat arbitrary, it is near the inversion point of the curves when relative transmission is plotted against angular distance from the point of maximum blackening on the arc from the 002 plane. Consequently, it was selected by the writers as the "X-ray angle," or the standard means of comparing the X-ray diffraction patterns. The 40-percent angle reported by Sisson and Clark (*30*) and by Sisson (*27, 28*) was not the same as that given here; however, they were both used for the same purpose, i. e., to measure the length of the 002 arcs.

ADJUSTMENT TO STANDARD INTENSITY

Since it is impractical to bring the maximum photographic density of each film to precisely the same point, it was necessary to determine the effect that the degree of exposure had upon the length of the 002 arcs. From this, a correction factor was evolved to convert all curves to a chosen standard maximum.

To determine this factor, numerous bundles of cotton fibers were prepared, representing types that would give a wide range in the length of the arc from the 002 plane. Several exposures of different time lengths were made of each bundle without disturbing the bundle between exposures. For a given bundle, the entire series of exposures were made consecutively and as rapidly as possible and all were developed under the same conditions. Moreover, the timing of the exposures was randomized, i. e., one exposure might be for 5 minutes, the next 30 minutes, and the next 15 minutes.

The results of five such series made on four brands of X-ray film available on the market, and with the standardized technique of bundle preparation, film development, and other procedures are given in figure 2. Regardless of the length of arcs in the diffraction pattern, the slopes of the lines within the range of recommended maximum blackening are all essentially the same. This important circumstance makes it possible to correct all fiber patterns, regardless of orientation, to a common opacity level by means of a single correction curve. The correction is most readily made by preparing a table (see table 19), to show the angle in degrees that is to be added to or subtracted from the observed angle for any photometer reading representing the maximum blackening between the limits set.

In the case of the microphotometer with which the observations above were made, the 180-scale division was the standard value of maximum blackening chosen (corresponding to a prescribed standard of 0.20 relative transmission) and the recommended limits for maximum blackening were readings of 140 and 220. Patterns of low photographic intensity (below 140) were centered on the photometer with much difficulty.

In the preliminary stages of the work, many "density," or exposure, series were made, using different kinds of film, different methods of bundle preparation, different developing techniques, and other procedures. It was found that most of these series gave essentially the same slope. The only noticeable exceptions occurred when a series

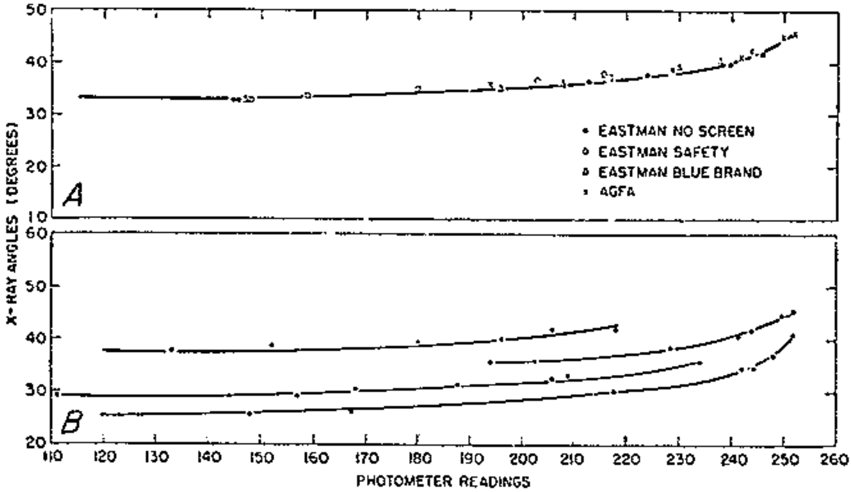

FIGURE 2.—X-ray angles, as related to the photometer readings at the point of maximum blackening of the 002 arcs: *A*, Composite curve, using the same sample of cotton with four brands of film; *B*, individual curves obtained each from a single bundle of cotton and a given brand of film. In practice, all X-ray angles are corrected to the 180 position on the photometer scale.

of films was very much underdeveloped and when some excessively fogged films were used. Neither can be tolerated in excess.

It is realized that emulsion characteristics may vary slightly from one batch to another of the same film, but this is difficult to determine. It seems reasonable to assume, however, that any variation between batches of the same kind of film is not so great as the variation from one kind to another. Consequently, if a change from one kind of film to another does not show a significant difference in the X-ray angles for a particular bundle of fiber, it may be assumed that no difficulties will be found because of variations between batches of film of the same kind, so long as the background is clear and uniform.

ALINEMENT OF FIBER BUNDLE WITH X-RAY BEAM

Another source of variation is the alinement of the specimen with respect to the axis of the X-ray beam as limited by the pinhole system.

Lack of alinement of the sample can be considered as made up of two components: (1) A linear displacement to one side of the axis of the beam; and (2) an angular displacement of the major fiber axis away from the perpendicular to the X-ray beam.

The first type of displacement is easily recognized by its results on the diffraction pattern—the two maxima points being of unequal intensity. In a routine method such a dissymmetry occurs to a greater or lesser extent in nearly every pattern. Even the most inexperienced technician can center the bundle of fibers, however, so that the two maxima do not differ by more than 1.0 or 1.5 percent. Any error in the measured angles that this degree of variation might cause has been shown to be concealed by other fluctuations.

In the tests for angular displacement, the bundle of fibers was placed perpendicular to the X-ray beam as accurately as could be judged by an experienced technician and three diffraction patterns were made without disturbing its position. It was then turned out of the 90° position, as much as was permitted by the nature and arrangement of the equipment, so that the X-ray beam made an angle of about 60° with the bundle axis, and three more patterns were made. At 90° the angles ranged from 43.8° to 44.4°, mean 44.1°; and at 60° they ranged from 44.6° to 45.1°, mean 44.9°. Repeated tests show that the angles increase slightly as the bundle is displaced from the perpendicular in regard to the X-ray beam. Even an inexperienced operator can usually judge the position of perpendicularity within 5°, however, so that a reasonable degree of care in placing the bundle in position will eliminate any significant error due to this cause.

DISTORTION OF BUNDLE

A brief test was made of the effect of bundle twist upon the X-ray angles. A bundle was photographed in the regular manner, and then, without disturbing its position in the clamps, one clamp was rotated through 90°. The bundle was X-rayed in this position and again with the clamp turned 45°. This was repeated with another bundle from a sample having greatly different orientation. The results of this experiment are given in table 1. As would be expected, the X-ray angles from the sample having a small X-ray angle were more greatly affected than those with a larger angle. On the whole, this is not a very likely source of error, but it is well to be conscious of the possibility that such an error can occur.

TABLE 1.—*Effect of bundle twist on X-ray angles*

Degree of twist	X-ray angle	
	Sample 8	Sample 36
	Degrees	*Degrees*
Untwisted	31.5	36.6
45°	32.2	36.9
90°	35.2	37.8

PINHOLE SIZE

One other variable in exposure technique—the effects of the pinhole size that limits the X-ray beam—must be considered. This will not change during the course of an exposure or be an uncontrolled factor, but in establishing a routine method it is essential to have the intensity of the X-ray beam as great as possible. Increasing the size of the pinhole increases the width of the diffraction line more than it actually increases the degree of blackening at a given point, but so long as this increase in width does not extend too far beyond the limits of the microphotometer slit, it has the same effect on the microphotometer readings as would result from an increase in X-radiation intensity.

In the experiments reported here, the pinhole systems were 0.014, 0.024, and 0.033 inch in diameter. In every case a 0.033-inch hole was mounted in the end of the collimator next to the X-ray tube and the size of the pinhole next to the sample was changed. It was found that the precision or repetition of the measurements is not significantly benefited by a decrease in pinhole size. It is concluded, therefore, that the shorter exposure time required with the larger pinhole is a real advantage.

The smaller pinhole gave a slightly larger X-ray angle (table 2), so that results obtained on different pinholes should not be used together, although many samples showed no significant differences between the 0.024- and the 0.033-inch pinhole.

TABLE 2.—*X-ray angles from three cottons, using pinholes of different sizes*

Pinhole size (inch)	Time of exposure	Photographic intensity	Cotton 1	Cotton 2	Cotton 3
	Minutes		*Degrees*	*Degrees*	*Degrees*
0.014	40	Light	34.4	36.4	37.2
.024	20	do	34.0	36.9	37.5
.033	10	Medium	33.8	35.5	34.3

FILTERS

To test the effects of the K_β radiation, exposures of the same sample were made, using different thicknesses of nickel filter. To absorb most of the K_β radiation, a sufficiently thick filter must be used to cause at least a doubling of the exposure time. For the development of a routine test method, this is of course highly undesirable unless considerable gain is made in the accuracy or precision of the angle determinations. Repeated measurements of the patterns made without a filter and of those made with the optimum filter showed neither a significant gain in the precision of the measurements of the film with the microphotometer nor a different value of the angles.

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PHOTOGRAPHIC DEVELOPMENT

All patterns should be developed under identical conditions, but the exact procedure adopted may not be important. There seems no reason, however, to depart from accepted practices. It is considered the best technique to move the negative around in the developer by hand in an irregular manner rather than by means of mechanical devices. Also, film and developer manufacturers specify the time and temperature considered best for development and provide charts that show the relation between these two factors.

The special film rack designed to develop several films at the same time is shown in figure 3. The film racks will hold 12 patterns and

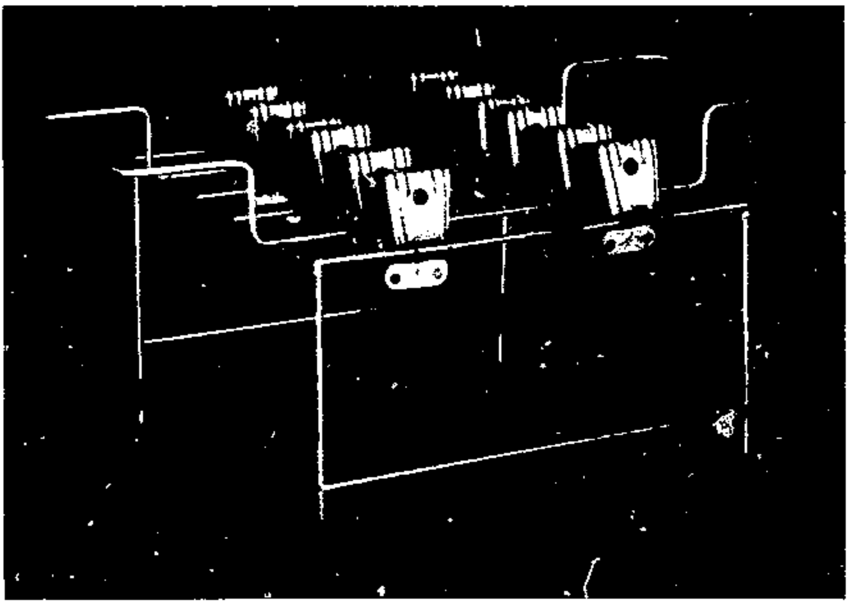

FIGURE 3.—Film rack designed to hold 12 patterns.

can be moved back and forth by hand in the tank for agitation. The tank is cubical in shape, 12 inches on a side.

The age of the developer may influence the X-ray pattern. When a 5-gallon tank is used, a number of films can be developed in the fluid for many weeks before it becomes exhausted. It is obvious, however, that the developer standing in the tank undergoes chemical change (oxidation) during this period, even though not being used.

The question arises as to how much the aging of the developer actually affects the measured X-ray angles. To determine this, a part of a batch of developer being discarded because of age and not because it had been "used up" was poured into a bottle and saved. Altogether, the stale developer had stood in an open tank for about 2 months and had then stood in the closed bottle with an air space above the liquid surface for another 2 months. Later on, this was poured into an extra tank and placed in the same water bath with a tank of freshly mixed developer.

A series of 10 diffraction patterns of the same bundle of cotton were made consecutively without disturbing the position of the sample between exposures, so that the conditions of exposure would be similar. These were then divided at random into two equal parts. The films were then developed, two at a time (one from each group), simultaneously in the two developers.

The stale developer tended to produce slightly larger X-ray angles. As shown in table 3, however, the difference between observations on the same bundle with a given developer is frequently greater than the differences shown by the two developers. Considering the small difference in these two groups and the fact that the stale developer was in much poorer condition than would probably be found in actual practice, it seems that deterioration of the developer is not a major source of error.

TABLE 3.—*Variation in X-ray angles caused by aging of photographic developer*

Test No.	Fresh developer	Stale developer
	Degrees	*Degrees*
1	35. 8	36. 0
2	35. 8	35. 4
3	34. 7	35. 6
4	34. 6	35. 9
5	34. 8	35. 1
Mean	35. 1	35. 6

BUNDLE PREPARATION

In an operation of the nature of the combing technique that is used in preparing the bundles of cotton there is always opportunity for many unknown and even unsuspected sources of variation. Since these cannot be isolated and examined, it seems most probable that the sum total of any such effects can best be noted in a comparison of the final product of different workers. Consequently, over the last several years every opportunity has been utilized to compare bundles prepared from the same sample by different experienced technicians. The degrees of deviation usually observed are shown in table 4. Because the preparation of the bundles is a skill that must be attained by considerable practice, it would be meaningless to compare the results obtained by inexperienced technicians.

A change from the wrapped bundles, as described by Berkley and Woodyard (*6*), was desirable for speeding up the process. A series of 50 samples covering a wide range of cellulose orientation were measured by both wrapped- and tied-bundle methods and the results examined statistically. The coefficient of correlation between X-ray angles and fiber strength for the tied bundles was −0.955 and for the wrapped bundles −0.934. The tied bundle can be prepared more quickly than the wrapped.

TABLE 4.—*X-ray angles made in 1937 and 1943 from duplicate samples of Stoneville 5 cotton grown at 6 locations in 1935*

Location	Block	X-ray angle obtained in— 1937[1]	1943[2]
		Degrees	*Degrees*
Florence, S. C.	1	31.7	32.1
	8	32.2	30.8
Marianna, Ark. (upland)	1	27.7	27.8
	8	30.0	28.2
Marianna, Ark. (delta)	1	26.6	27.3
	8	31.0	30.0
Stillwater, Okla.	1	25.1	26.1
	8	29.7	27.6
College Station, Tex.	1	27.7	28.6
	8	27.6	28.4
Lubbock, Tex.	1	33.9	35.4
	8	34.0	36.0

[1] Angles obtained in 1937 while the X-ray method was in process of development.

[2] Angles on the same samples in 1943 after numerous changes in the technique, as well as operators, had been made. The principal difference was a lower discrepancy between blocks 1 and 8 in the 1943 results.

TENSION

The natural waviness of the fiber varies with moisture content, and paralleling in it is influenced by the crossing due to bends or folds. Tension applied to the bundle being X-rayed tends to remove waves or kinks and to draw them more nearly parallel. Several bundles from cottons of different X-ray angles were photographed at a wide range of tensions under otherwise comparable conditions. The resulting angles were plotted against the tension, giving the curves shown in figure 4.

As these curves do not become completely horizontal at any point, it was necessary to choose arbitrarily a value for a tension low enough for all samples to withstand it without breaking and high enough to avoid the steep slopes of the first part of the curves. This value has been taken as 10 pounds for the tied bundle and 15 for the wrapped.

To test whether maintaining tension on a bundle over a period of time will affect the X-ray angle, some bundles were placed in the tension device, a tension of 10 pounds was applied, and they were immediately X-rayed. They were then left undisturbed for several days and during this period were photographed at frequent intervals. The results indicate that a tension of 10 pounds is insufficient to cause a significant degree of creep.

SIZE OF BUNDLES

The fact that tension changes the X-ray angles makes it necessary to control the size of the bundle used. This phase of the study shows variable results, as the X-ray angle in certain samples varies little

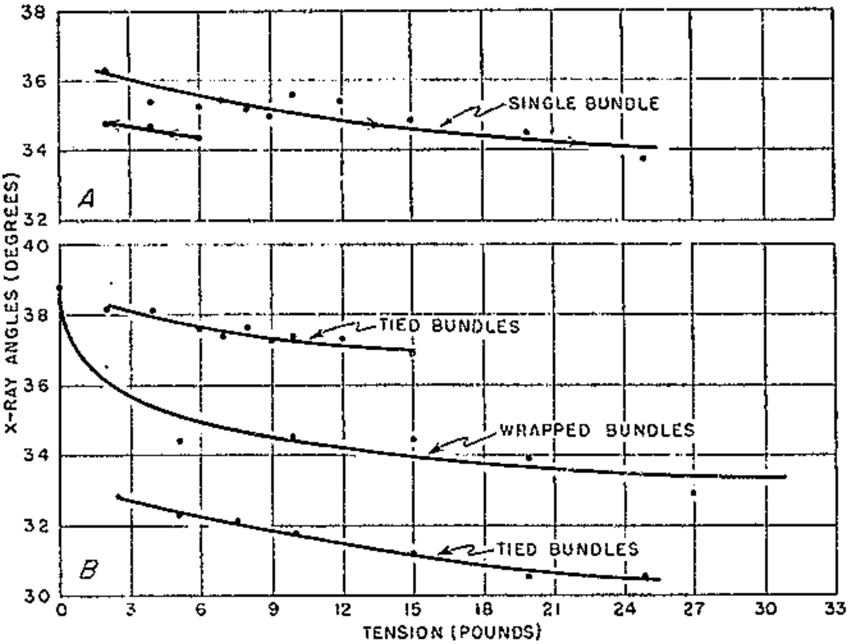

FIGURE 4.—Changes in the X-ray angle when tension was applied to the bundle being photographed: *A*, Results on one bundle, showing decrease in X-ray angle as the tension was increased and increase in the angle as the tension was released; *B*, curves representing averages of five or more samples—from tied and from wrapped bundles.

with a 25-percent increase or decrease in bundle weight, whereas that of other cottons varies considerably with changes in bundle size. An example of the X-ray angle of three bundles for each size for a given cotton is as follows: Average size, 41.8° to 42.2°; 20 percent below average, 39.3° to 41.7°; and 40 percent above average, 41.7° to 44.3°.

In general, however, it is not difficult to check results, irrespective of sample, when the bundles are kept near the same diameter. A certain deviation of error in bundle weight must be accepted, and a tolerance arbitrarily set up. A tolerance of not more than ±1 mg. in bundle weight for a given cotton has been chosen as the deviation permitted in the work of this laboratory. This naturally is a rough control, since the weight for a bundle 1 mm. in diameter may vary from approximately 20 mg. in short cottons to 35 mg. in long sea-island cottons.

MEASUREMENT OF PATTERN

Several possible sources of variation must be considered in measuring the X-ray diffraction patterns. These may be roughly divided into errors that are inherent in the microphotometer, those due to variations in techniques of different operators, and those due to variable factors in the films themselves. Fortunately, all these sources have been found to be relatively free from error, owing in part to the fact that many errors tend to cancel out on opposite sides of the diffraction arc; i. e., an error that raises the value of the angle on one side of a maximum usually lowers it to the same degree on the other.

One of the most time-consuming operations, and the one that is found most difficult to new technicians, is that of centering the film on the stage For this reason, measurements were made on several films, in the manner to be described for a single film, to determine how much error could be allowed in the centering.

A film was centered accurately by a skilled operator (this can be done to within 0.05 mm.), and the angle measured. The film was then displaced 2 mm. to one side so that the light beam traced the outer edge of one arc and the inner edge of the other, and the angle was measured again. This displacement did not change the results significantly, since it is less than the standard error of $\pm 1°$ found for 2,000 observations. Since even an inexperienced worker can center a film within 0.2 or 0.3 mm., it was not thought necessary to make measurements for intermediate displacements. There is quite definitely a limit to the extent of displacement that can be permitted, however, and careless centering of the film should not be permitted.

Experiments were also conducted with deliberate rotational displacements from the maxima of the arc on the stage. Consideration of the nature of the measurements readily shows in this instance that so long as the galvanometer readings at the true maxima and minima points are obtained, it does not matter what number is used on the circular scale to correspond to these points. Since anyone can find these points with the microphotometer, there is no need for having a displacement error in the rotational direction. If the galvanometer readings at 0° and 90°, however, are used arbitrarily without consideration of maxima and minima, an error will result.

From time to time, the photocell in the microphotometer has been replaced. Photocells of the blocking-layer type of the same and different makes were compared, but no significant difference in the X-ray angles was observed.

Discussion and Conclusions

The X-ray method is empirical and has been developed purely on the basis of whether it would work, i. e., give results valuable for a specific purpose. There are numerous sources of error, but with care these errors can be controlled within limits satisfactory for routine testing. In the development of the method, the purpose has been to use the X-ray angles as a measure of the tensile strength and spinning quality of the fibers. Accordingly, many decisions have been influenced by correlations of the results.

RELATION TO YARN STRENGTHS

By Earl E. Berkley and H. D. Barker[8]

General Background

The value of a sample of cotton is related to the quality of product into which it can be fabricated. The cotton buyer must estimate that value rapidly and with considerable precision. As an aid to this, a set of standard grades and staples has been adopted by the United States Department of Agriculture (*35, 36, 37*), and Lord (*17*) discussed staple length for use in England.

In addition to these, however, for improving American cottons, definite measures of certain fiber characteristics—length, tensile strength, fineness, and other properties—are needed by the breeder. Each year numerous new strains and progenies resulting from crosses or selections must be compared. It is necessary, therefore, that the methods be relatively rapid, adaptable to routine procedure, and reproducible under the conditions imposed by the tests.

The fibrograph, developed by Hertel (*12*), gives a rapid means of estimating length; and the Pressley (*23*) strength tester will give a comparative index of fiber strength. When fiber strength is reduced by field damage, however, it is occasionally desirable to substitute for direct strength measurements some type of fiber strength estimate based on fiber structure.

Microscopic techniques were used in lieu of strength measurements by Morey (*20, 21*), who found that the orientation of the cellulose as shown by dichroism was related to the tensile strength of the cotton as measured by the Chandler bundle method (*22*). The microscopic methods are laborious, however, and for this reason studies were made on the use of X-ray diffraction technique. The background and detail of this method are described by Berkley and Woodyard in another section of this publication (pp. 3 to 14). The use of such a method depends on the relation between the results obtained and the use value of the cotton. Some measure of use value must be chosen,

[8] The authors are indebted to J. O. Ware, in charge of the breeding program of this Division, and to the following representatives of the field stations who furnished samples: Alabama—H. B. Tisdale and J. B. Dick, Auburn; Arizona—the late C. J. King, Sacaton; Arkansas—D. B. Shank, Marianna; California—G. J. Harrison, Shafter, and E. G. Noble, Bard; Florida—M. N. Gist, Gainesville; Georgia—W. W. Ballard, Experiment, and J. H. Turner and J. G. Jenkins, Tifton; Louisiana—C. B. Haddon, St. Joseph, and H. B. Brown and J. R. Cotton, Baton Rouge; Mississippi—J. W. Neely, Stoneville, and J. F. O'Kelly, State College; New Mexico—A. R. Leding, State College; North Carolina—P. H. Kime, Raleigh, and R. H. Tilley, Statesville; Oklahoma—H. E. Dunlavy, Stillwater, and L. M. Parrott, Tipton; South Carolina—W. H. Jenkins and E. E. Hall, Florence, and R. S. Bailey, John Island; Tennessee—D. M. Simpson and N. I. Hancock, Knoxville, and B. P. Hazelwood, Jackson; Texas—D. L. Jones, Lubbock, J. R. Quinby, Chillicothe, H. O. Hill, Temple, T. R. Richmond and D. T. Killough, College Station, and D. R. Hooton, Greenville.

and it was felt that tensile strength of fiber was not sufficient. These studies, therefore, include the skein strengths of some 1,430 samples of cotton representing more than 100 varieties, strains, and crosses, during 8 years of planting at 29 locations, representing both the irrigated and the nonirrigated parts of the Cotton Belt.

Turner and Venkataraman (*33*) developed a regression equation for predicting the strength of the highest practical warp count from six properties of cotton fibers. Kapadia (*14*) reworked a part of their data and criticized their methods and conclusion. He was of the opinion that fiber fineness was more important than fiber length and that fiber strength was also a major element in estimating the value of a cotton. Ahmad (*1*), discussing Turner and Venkataraman's findings, stated that "fibre length was most closely associated with highest standard warp count and that fibre weight per inch came next in order."

The correlation coefficients of ribbon width, convolutions, fiber strength, and rigidity were doubtfully significant when compared singly with skein strengths. The multiple correlation coefficient between two or more properties showed that fiber length and weight per inch accounted for 84 percent of the variability, while all the six properties combined accounted for only 86 percent. Hutchinson and Govande (*13*) obtained relatively high *r* values when they used mean length with fiber strength and fineness correlated with spinning value both within and among species. The fiber strength used by the Indian workers in their correlations was obtained from single fibers with a span between testing jaws of 1 cm. and is not identical with the bundle strength reported here; furthermore, they did not use fiber structure as shown by X-ray diffraction patterns.

Length measure is generally recognized as the most important individual fiber property ordinarily determined for predicting the strength of singles yarn, particularly at the finer counts. Turner (*32*) reviewed the early reports on spinning and Clegg's paper on fiber properties (*10*) and pointed out that fiber strength is of little value in making predictions of the skein strength of singles yarn. Köhler (*16*) stated that only 10 to 20 percent of the fiber strength is evident in the yarns.

The present study includes the relations between the fiber structure as measured by the X-ray method and: (1) The fiber strength by the Chandler bundle method and the Pressley strength index; (2) skein strengths of yarns of various counts with fineness and/or length taken into account. For purposes of comparison, the fiber strength was substituted for X-ray angles in certain of the sets of data.[9]

MATERIALS AND METHODS

The yarn-strength studies included more than 3,000 individual samples of cotton, 1,430 of which were spun. A certain number of the spinning samples represented duplicate blocks from the same variety

[9] Since this manuscript was prepared there has come to the writers' attention the following processed report, which includes certain of the data represented here but is not organized to show varietal and environmental effects, which may be of primary interest to the cotton breeders and producers:

WEBB, R. W., and RICHARDSON, H. B. RELATIONSHIPS BETWEEN PROPERTIES OF COTTON FIBERS AND STRENGTH OF CARDED YARNS. Office of Mktg. Services, War Food Admin. 58 pp., illus. Washington. 1945.

at a given location. Each sample of cotton in the spinning test was spun into three counts, and each group spun into common counts was examined separately. Assuming the same accuracy in the methods, skein strength should be more closely associated with the fiber strength than with the X-ray angles, since both the fiber and yarn strengths were affected similarly by field damage. The use of the X-ray method heretofore has been confined to breeding stock, rather than mill samples; however, it will be compared with the strength methods on samples grown as nearly as possible under ordinary field or agricultural practice.

The samples used in these studies were divided into four groups: Regional variety studies, regional spinning studies, variety and strain tests, and special studies.

REGIONAL VARIETY STUDIES

Spinning studies and fiber measurements were made on 758 samples from blocks 1 and 8 of the regional variety study, which was composed of 16 varieties grown at 8 locations for 3 years, 1935–37. Duplicate samples were not spun for 9 varieties at Stillwater, Okla., in 1936 and for 1 at Lubbock, Tex., in 1937, where blocks 1 and 8 were combined. The fiber properties included fiber strength (Chandler bundle method), upper quartile fiber length, fineness by the weight-per-inch method, and X-ray angles. Other fiber measurements made are not discussed here.

REGIONAL SPINNING STUDIES

The regional spinning studies are a continuation of the varietal strain study, 1938–42, inclusive. They were extended to the irrigated belt and were a part of the coordinated Federal-State cotton research program. They included numerous commercial varieties and new strains being developed for commercial plantings.

VARIETY AND STRAIN TESTS

The study of varieties and strains was also a part of the coordinated Federal-State cotton research program. It included commercial varieties and new strains, and various progenies, before they were increased sufficiently for spinning tests. For the most part the samples submitted for X-ray tests were also examined by the Pressley strength method so that comparisons of the structure and the Pressley strength index could be made. The variety-strain tests involved both the old varieties, which were grown for checks, and the new strains, including in some cases F_1 and succeeding generations produced from crosses of widely different cottons. They also included selections from selfed lines of old strains.

SPECIAL STUDIES

Special studies included the sea-island strain tests and American-Egyptian cottons, grown both as varietal and environmental tests.

The methods used have been described. The X-ray technique has been discussed by Berkley and Woodyard elsewhere (*6*) and in this bulletin;[10] the Pressley method (*23*) and the Chandler bundle method,

[10] Experimental Background of X-ray Method, p. 3.

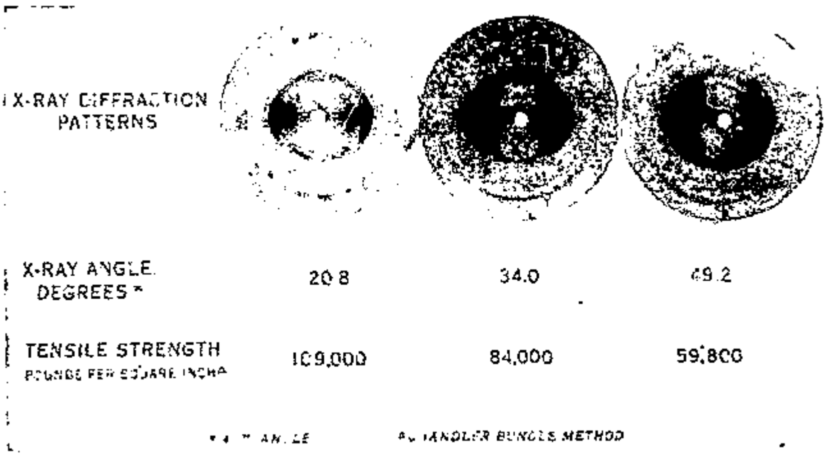

FIGURE 5.—X-ray diffraction pattern, X-ray angle, and tensile strength of a very strong, an intermediate, and a very weak cotton. These cover the range of X-ray patterns that would be expected from ordinary field-grown cottons.

fiber length (Suter-Webb sorter method), and weight-fineness (*24*) have been discussed in earlier publications. The fibrograph, on which the upper half mean length was determined, has been described by Hertel (*12*). The spinning study was made by the Cotton Branch, of the Production and Marketing Administration. The spinning and the fiber data, other than a part of the X-ray angles and the Pressley indices of the variety-strain test samples, have been reported by the Cotton Branch.[11]

[11] All in processed form, as follows:

CAMPBELL, M. E. PRELIMINARY REPORT OF COTTON SPINNING AND RELATED FIBER STUDIES, IN CONNECTION WITH THE REGIONAL VARIETY SERIES, CROPS OF 1935 AND 1936. Address, Amer. Soc. Agron., New Orleans, La. 26 pp., illus. 1939.

——— and LEE, R. L., JR. SPINNING AND FIBER PROPERTIES OF SIX AMERICAN UPLAND COTTONS GROWN AT STONEVILLE, MISS., CROP OF 1939. U. S. Dept. Agr. 17 pp., illus. 1940.

UNITED STATES AGRICULTURAL MARKETING ADMINISTRATION. RESULT OF TESTS OF SEVEN COTTONS GROWN AT STONEVILLE, MISS., CROPS OF 1940. U. S. Dept. Agr. 4 pp. 1942.

——— RESULTS FROM SPINNING AND FIBER TESTS ON SOME COTTONS GROWN IN THE SOUTHEAST, CROPS OF 1939 AND 1940. U. S. Dept. Agr. 8 pp. 1942.

UNITED STATES AGRICULTURAL MARKETING SERVICE. RESULTS OF FIBER AND SPINNING TESTS OF SOME VARIETIES OF COTTON GROWN IN TEXAS, CROP OF 1940. U. S. Dept. Agr. 8 pp. 1941.

UNITED STATES FOOD DISTRIBUTION ADMINISTRATION, COTTON AND FIBER BRANCH. SPINNING AND FIBER TEST RESULTS FOR SOME COTTONS GROWN IN TEXAS AND OKLAHOMA, CROPS OF 1941 AND 1942. U. S. Dept. Agr. 8 pp. 1943.

——— SPINNING AND FIBER TEST RESULTS FOR SOME COTTONS GROWN IN CALIFORNIA, ARIZONA, AND NEW MEXICO, CROPS OF 1941 AND 1942. U. S. Dept. Agr. [9] pp. 1943.

——— RESULTS OF SPINNING AND FIBER TESTS OF SOME COTTONS GROWN IN MID-SOUTH, CROPS OF 1941 AND 1942. U. S. Dept. Agr. 13 pp. 1943.

——— RESULTS OF SPINNING AND FIBER TESTS OF COTTON GROWN IN THE SOUTHEAST, CROPS OF 1941 AND 1942. U. S. Dept. Agr. 11 pp. 1943.

RESULTS

CELL-WALL STRUCTURE AND FIBER STRENGTH

An example of the relation between the structure of cotton fibers as shown by X-ray diffraction patterns and fiber strength is illustrated in figure 5, where the length of the 002 arcs, as measured by the X-ray angles, varies in proportion to the fiber strength. The pattern to the extreme left [12] with the short arcs is from fibers in which the cellulose lies essentially parallel with the fiber axis, that in the middle with the intermediate arcs from cotton with an average spiral, and the pattern on the extreme right with very long arcs from a cotton with a very low or flat spiral structure.

X-ray angles and fiber strengths are given under each pattern. The angles shown cover the extreme range ordinarily found in upland cottons. The fiber-strength determinations are limited, however, by the technique used and may vary outside these limits, since special hybrids and sea-island cottons may be stronger by a given method of test, and badly damaged cottons may be weaker than the strength values given here. The cotton showing the 20.8° angle and 109,000 pounds strength was probably stronger than these figures indicate, since only 3 bundles out of 30 broke. The rest were so strong that they slipped in the testing jaws.

The general relation between fiber structure and strength, which is characteristic of the upland cottons, is illustrated in figure 6, which shows the fiber strength of the regional variety study plotted on the ordinate and the X-ray angles on the abscissa. Each plotted point is an average of two blocks at a given location and year. It will be observed that the band of spots is consistent throughout its length and no indication of curvature was found. The heavy line represents the regression equation for estimating the strength of the fiber from the X-ray angles. Certain of the varieties used in this study were somewhat different from the average upland cottons, and some field damage was indicated from the color [13] and low grade of the samples.

The fiber strength (Chandler bundle method) and the strength index (Pressley method) are reported in different units; therefore, the regression equations for predicting their values from the X-ray angles are different. When a given strength method is used, the relation between strength and structure, as shown by the regression equation obtained for upland cottons, is also different from that of sea-island or of American-Egyptian cotton (table 5). Since the upland cottons are classified as *Gossypium hirsutum* L. and the sea-island and American-Egyptian cottons as *G. barbadense* L., it is desirable to know the species and, if possible, the variety of a sample when examining it by the X-ray method.

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[12] Sample of Beasley's (3) triple hybrid cotton furnished by Thomas Kerr, Raleigh, N. C. For outstanding spinning results on this cotton, see the following reference:

CAMPBELL, M. E. SOME SPINNING TEST RESULTS OF INTEREST TO COTTON MANUFACTURERS. Address, Ann. Convention of the Southern Textile Assoc. Myrtle Beach, S. C. U. S. Dept. Agr. 7 pp. 1941. [Processed.]

[13] Unpublished data from the files of Dorothy Nickerson, Color Laboratory, Cotton Branch, Production and Marketing Administration.

TABLE 5.—*Coefficients of correlation (r value), regression equations, and standard errors of estimate for the relationships of the X-ray angles and the fiber-strength indices, Pressley method, for three types of cotton*

[y=Fiber strength, pounds per milligram]

Cotton	Number of observations	r values	Regression equation	Standard error of estimate
Sea-island	161	−0.6691	y=16.5286−0.2286x	0.1532
American-Egyptian	93	−.9366	y=15.8740− .1800x	.1345
American upland	905	−.6418	y=12.3105− .1497x	.5336

The regression for sea-island differs significantly from that for American-Egyptian cottons, and the regressions for both of the barbadense types differ markedly from that for American upland. If combined and compared with American upland cottons, which are on an entirely different level, as shown in figure 7, some idea of species difference can be obtained. The difference in slopes are statistically different, but the number of samples in the American-Egyptian and sea-island cottons were relatively small and somewhat different slopes would be expected for other sets of data. According to these data,

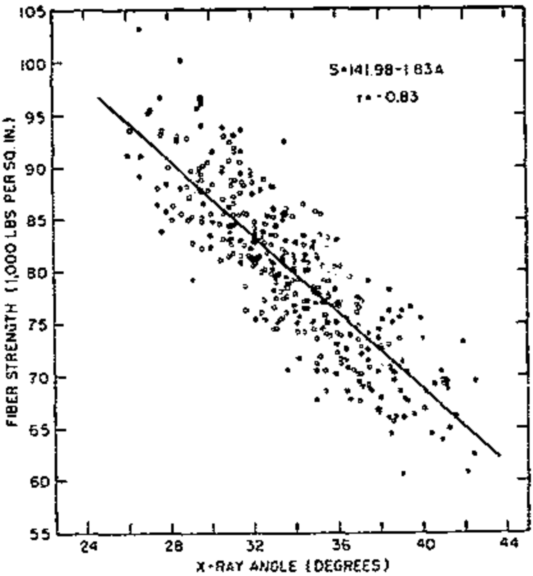

FIGURE 6.—Scatter diagram of the regional variety study, with fiber strength in thousands of pounds per square inch on the ordinate and the X-ray angles on the abscissa. The heavy ink line represents the regression equation of fiber strength on the X-ray angle. Each plotted point represents the average of two samples from a given variety, station, and year.

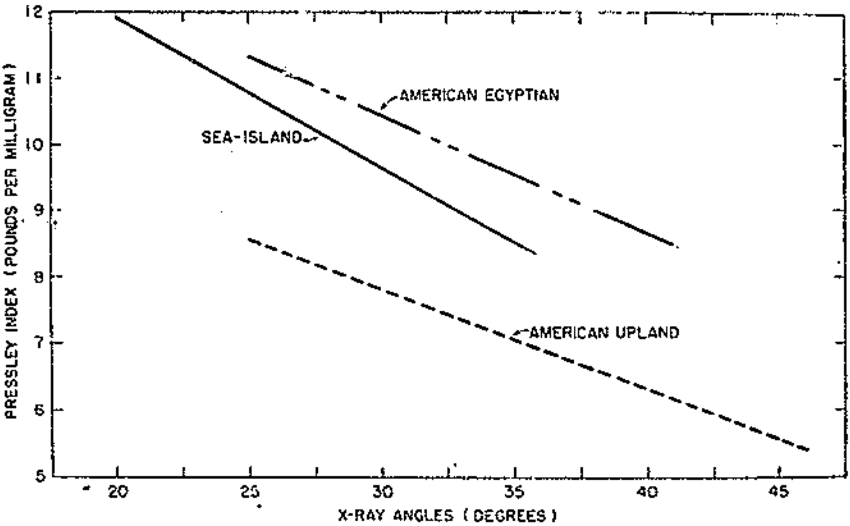

FIGURE 7.—Regression lines from equations for American-Egyptian, sea-island, and American upland cottons.

there is an average difference of approximately 2 pounds[14] in the strength index between the American upland cottons and the Egyptian and sea-island cottons for a given X-ray angle.

The mean squares for X-ray angles and fiber strengths, *r* values, regression equations, and standard error of estimate for the X-ray angles and fiber strength of the regional variety study are shown in table 6. When measured by the conventional F test, all the main effects and interactions are significantly greater than error. In both the X-ray angles (variance of X) and the fiber strength (Y) environment was numerically a greater contributor to variance than was variety. The varietal effect was highly important, however, and, since the varietal characteristics can be changed by careful breeding, variety becomes the most important controllable factor in the improvement of cottons.

A small part of the location and yearly effects may be attributed to field damage; however, the environmental conditions of growth undoubtedly were responsible for most of it. At Baton Rouge in 1937 and, to a certain extent, for all years, considerable field damage was indicated. Even where field damage is not pronounced in all strains, one variety may show a different strength from that of another for the same X-ray angle similar to different species but on a smaller scale. This may be due to the fact that certain strains are earlier than others, and all were picked on the same date, so that differential field damage could have occurred.

[14] A difference in Pressley index of 2.00 = 21,503.2 pounds per square inch in terms of the Chandler bundle method. (See Reports of Spinning Tests by the Cotton Branch, P. M. A. (footnote 11), where strength in 1,000 pounds per square inch = $10.8116X - 0.12$, where X = Pressley index.) This formula applies to American upland cottons of medium- to short-staple lengths and does not necessarily indicate the differences in tensile strengths of the two species.

TABLE 6.—*Variance analysis and correlation data for X-ray angles and fiber strength from the regional variety study for 3 years, 1935–37*

[X=X-ray angles, in degrees; Y=fiber strength, 1,000 pounds per square inch (Chandler bundle method); y=estimated fiber strength]

Source of variation	Degrees of friction	Mean squares		r value	Regression equation	Standard error of estimate
		X	Y			
Total	767	12.5858	60.203	−0.8340	$y=141.719-1.824x$	4.2839
Years	2	438.4520	1186.138	−.9904		
Location	7	622.8606	2887.797	−.9397	$y=148.50-2.023x$	1.7568
Varieties	15	212.7139	1001.167	−.3500	$y=142.41-1.844x$	2.3324
Blocks within location	8	7.8542	31.609	−.8380		
Years×blocks within location	16	1.6831	8.194	.4105		
Years×location	14	32.8267	243.831	−.4889	$y=158.379-2.3141x$	1.1158
Years×varieties	30	2.1310	40.528	−.0297		
Location×varieties	105	1.4371	9.903	−.2209		
Years×location×varieties	210	1.0141	7.561	−.2618		
Error	360	.6904	2.585	−.0665		

Certain varieties, for example, Stoneville 5, Cook 912, Farm Relief, and Half and Half, usually show lower fiber strengths and, to a certain extent, lower skein strengths for a given X-ray angle than the other strains on the average, whereas Wilds 5 and Delfos (Missdel) 4 are consistently stronger (fig. 8). Further studies on the effects of environment on these relationships are being made. A part of the difference can no doubt be assigned to the method of test, since it is possible that extremes in length may influence the Chandler bundle method, and fineness may be a factor in the Pressley method of determining strength. Figure 8, however, shows that strains of cotton may be fundamentally different.

A somewhat better relationship of structure to strength could be obtained by omitting the samples that are field damaged, but this, of course, is not possible since the damage is not always visible.

The mean squares for strength index (Pressley method) and for X-ray angles, the r values, regression equations, and standard error of estimate when these two factors are correlated for the American upland cottons are shown in table 7. The r values are lower than those found when the fiber strength was determined by the Chandler bundle method. In one set of 21 samples of American-Egyptian cotton where special care was taken to keep the methods constant, the r value was −0.97 between the X-ray angles and the Pressley indices.

The r values differ and regression equations show considerable variation in slope going from total to station years within regions to within station years (varietal effect) and from one region to another. Since the level of test at different laboratories is more likely to affect the between groups, the regression equation for within groups would probably be more satisfactory for prediction purposes

TABLE 7.—*Variance analysis, r values, and regression equations for X-ray angles and fiber strengths by regions and for the total of all regions* [1]

[X=X-ray angles, degrees; Y=Pressley index; y=estimated fiber strength. The "among groups" is the station years and the "within groups" represents the varietal effects]

Region and covariance	Degrees of freedom	Mean squares		r value	Regression equation	Standard error of estimate
		X	Y			
Southeast:						
Total	460	8. 6233	0. 4584	−0. 6500	y=12. 2885−0. 1499x	----------
Station years	11	99. 6200	9. 7469	−. 7630	y=15. 381 − . 2387x	----------
Variety within station years	449	6. 3939	. 2309	−. 6104	y=11. 1082− . 1160x	----------
Mid-South:						
Total	168	7. 7638	. 3151	−. 6172	y=11. 356 − . 1243x	----------
Station years	12	32. 4833	2. 3969	−. 6074	y=12. 995 − . 1710x	----------
Variety within station years	156	5. 8622	. 1413	−. 6727	y=10. 6575− . 1045x	----------
Texas-Oklahoma:						
Total	175	9. 6791	. 6473	−. 6644	y=13. 2196− . 1718x	----------
Station years	15	50. 5260	4. 4737	−. 7582	y=15. 0344− . 2249x	----------
Variety within station years	160	5. 8498	. 2886	−. 5802	y=11. 7512− . 1289x	----------
Southwest:						
Total	98	10. 2717	. 4907	−. 5818	y=11. 515 − . 1272x	----------
Station years	7	34. 8900	3. 3269	−. 2379	y= 9. 657 − . 0735x	----------
Variety within station years	91	8. 3780	. 2725	−. 8004	y=12. 1091− . 1444x	----------
All regions:						
Total	904	8. 8878	. 4836	−. 6418	y=12. 3105− . 1497x	0. 5336
Station years	48	53 1429	5. 0243	−. 6911	y=11. 4900− . 2125x	. 3735
Variety within station years	856	6. 4062	. 2200	−. 6374	y=11. 2971− . 1205x	. 3590

[1] Standard error of estimate values are given for all regions. These data represent both 1941 and 1942, except for the Southeast where only 1942 Pressley index data were available.

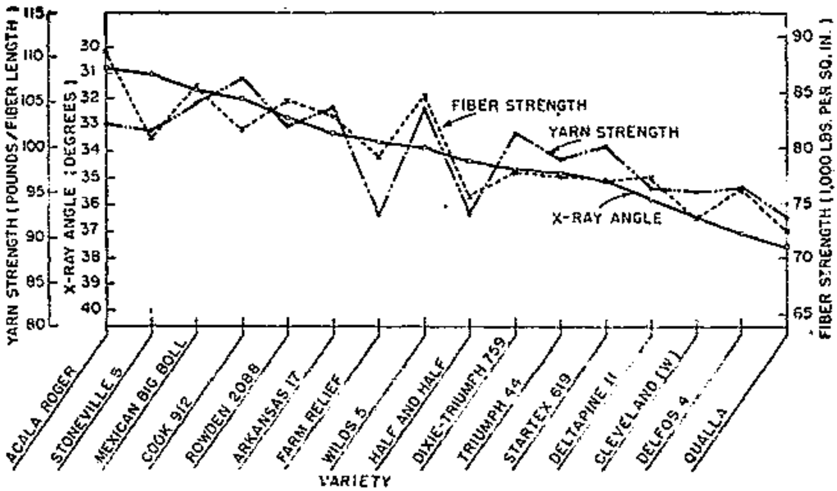

FIGURE 8.—Comparison of the X-ray angles, fiber strengths, and yarn strengths divided by the fiber length for the regional variety study. Each plotted point represents the average of two observations for a given variety for three consecutive years at eight locations.

where it is desired to estimate the strength index from the X-ray angles. Since the X-ray method serves best in breeding studies, little or nothing will be gained by converting the X-ray angles into strengths.

FIBER STRUCTURE AND YARN STRENGTH

The properties of a yarn are dependent upon numerous fiber properties and processing effects, all of which should be taken into consideration. The fiber properties in turn are influenced by heredity, environment, and field or storage damage. It is necessary, therefore, in making specific predictions that the data be analyzed in such way as to segregate as many as possible of these variables. Where it was practicable to do so these data, consequently, were broken down to show main effects and interactions so as to get a measure of the various contributors. The data do not lend themselves to an examination of the variations due to the spinning process. These variations, according to Campbell (*8*), are appreciable, and a part of the variability not accounted for here may be attributed to the manufacturing process.

Space does not permit the presentation of all the data or the detailed analyses. The examples used, however, are, as far as possible, representative of the results as a whole.

Certain of the individual fiber properties, for example, the length and occasionally the fineness as measured by weight-per-unit length, showed a relatively high coefficient of correlation with the yarn strength (table 8). For the regional variety study, both length and fineness gave r values of 0.88 when the varietal means were correlated with the weighted skein strengths of 22s yarn.[15] When fiber strength was correlated with skein strength (22s yarn), an *r* value of 0.76 was obtained, whereas X-ray angles and skein strengths (22s yarn) gave an *r* value of only −0.39. When fiber lengths and X-ray angles, for example, were combined into the product $(2-L)X$, where L=fiber length and X=X-ray angles, and correlated with yarn strengths, higher correlations were obtained (table 8). Since in these studies, the length and fineness were so closely associated with each other and since length was highly correlated with skein strength, it was not possible to differentiate clearly between the structure and the strength effects.[16]

The results agree reasonably well for samples represented in groups 1, 3, and 4. In group 2, which was spun into 22s, 28s, and 44s, it is indicated that numerous cottons, which otherwise were long enough to spin into 22s, 36s, and 50s but had probably received field damage, were thrown into this group. This is indicated both from the results and the grades and color of the cotton. Since group 1 is very small, it is suggested that little reliance be placed in the results from groups 1 and 2.

The coefficient of correlation (*r* value) obtained by Webb and Richardson (see footnote 8) for the total or over-all mixture of varietal and environmental effects is in reasonably good agreement with those reported here for "total." They report an *r* value of 0.824 when upper quartile fiber length and fiber strength were correlated with skein strength of 22s yarn. For the same data, except that X-ray angles were substituted for fiber strength, the writers obtained an *r* value of 0.712 when the product of upper quartile fiber length and X-ray angle were correlated with weighted skein strength of 22s yarn. The *r* values, for all effects, were found to be greater when fiber strength was used in place of X-ray angles in the correlations with skein strength of weighted 22s yarn.

Since the *r* values reported by Webb and Richardson were obtained for the total, or over-all, effects they should not be compared with the *r* values calculated for varietal or environmental effects reported in tables 8 and 9 of this bulletin. The reason total or over-all associations may be misleading when applied to specific associations may be illustrated by the following example: The relation between fiber length and skein strength is strongly positive for varietal effects but is usually nonsignificant or occasionally negative for environmental effects. The total, therefore, would appear to represent an intermediate value that may not in certain instances meet the needs of cotton breeders.

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[15] Weighted 22s differ from 22s since they are adjusted by the performance of the other two counts, given in the preliminary report by Campbell (see footnote 11, p. 18).

[16] Fiber length is directly related to skein strength, whereas X-ray angles and fineness, as expressed by weight per inch, are inversely related.

765235—48——4

TABLE 8.—*Correlation coefficients (r values) of fiber properties and weighted 22s yarn strength,[1] calculated from the varietal means, regional variety study*

FIBER PROPERTIES ALONE

Factors used in correlation	r values
Length and fineness	−0.91
X-ray angle and fiber strength [1]	−.85

FIBER PROPERTIES AND YARN STRENGTHS

Factors used in correlation	r values
Skein strength of 22s yarn and fiber properties:	
Length	0.88
Fineness	−.88
Fiber strength [2]	.76
X-ray angle	−.39
Fiber strength×length	.95
Fiber strength×length divided by fineness	.94
Fiber strength divided by fineness	.94
X-ray angle (2−length) fineness	−.94
X-ray angle divided by length	−.93
X-ray angle×fineness	−.90

[1] See Campbell citation in footnote 11, p. 18.
[2] Chandler bundle method.

The regional variety study was symmetrical; therefore, the variety and the environmental effects and their interactions were separated (table 9). Comparing the mean squares, the varietal effect was numerically the greatest contributor to variance, both in regard to the length and structural factors and the skein-strength effect. Location was the second greatest contributor for the length and structural factors, whereas year was the second greatest contributor for yarn strength. For yarn strength, all major effects and all interactions were significantly greater than error. In fiber properties, all effects were significantly greater than error. The *r* value for total was 0.89 without Baton Rouge, and 0.71 including Baton Rouge. The *r* value for varietal effect was 0.94 when Baton Rouge was omitted and 0.93 when it was included. This may account for as much as 88 percent of the variations in the yarn strengths. The spinning technique undoubtedly accounts for a large part of the rest.

In the relationship of X-ray angles and fiber strength the *r* values for location and season were higher than for variety (table 6), whereas in the spinning studies the correlations between fiber properties and skein strength were higher for the varietal effect. In the fiber studies, strength is influenced by structure, which may be altered for any given variety by the environmental factors. In the spinning studies, however, yarn strength is dependent on many factors, among which are fiber length, fineness, and strength. Fiber length is probably the greatest single contributor to yarn strength, particularly at the higher counts, and it may be less affected by environment than the strength or other fiber properties used in these correlations.

TABLE 9. —*Variance analysis of fiber properties and skein strength and correlation coefficients (r values) for the 2 replicates of 16 varieties of cotton grown at 7 and 8 locations,*[1] *respectively, for the 3 years, 1935–37*

[*X*=Product of complement of X-ray angle and upper quartile fiber length—(100−X-ray) u. q. l.; *Y*=weighted skein strength of 22s yarn

Variance	Omitting Baton Rouge				Including Baton Rouge			
	Degrees of freedom	Mean squares		*r* value	Degrees of freedom	Mean squares		*r* value
		X	*Y*			*X*	*Y*	
Total	661	------	------	0.8905	757	------	------	0.7124
Blocks within location	7	14.2040	38.0557	.4310	8	12.4299	33.7288	.4241
Years × blocks within location	14	14.6867	11.7857	.4362	16	14.5715	12.2306	.4808
Varieties	15	2745.6521	5110.4573	.9387	15	138.2743	5333.5980	.9334
Location	6	996.2483	2300.1400	.6333	7	853.9398	5817.9057	.3718
Year	2	133.8180	3232.9850	.7603	2	248.1870	7344.8300	.9059
Variety × location	90	10.6725	48.6743	.4866	105	9.8378	68.6730	.3955
Variety × year	30	6.7834	16.7760	.2848	30	7.7915	13.1603	.1679
Location × year	12	110.8378	1262.8450	.7724	14	107.9413	1842.8686	.7744
Variety × location × year	180	5.4312	25.1658	.4272	210	5.1882	26.2231	.4041
Error	305	2.6533	9.4629	.1066	350	2.4474	9.6243	.1090

[1] The samples from Baton Rouge were low in grade and showed distinct signs of field damage.

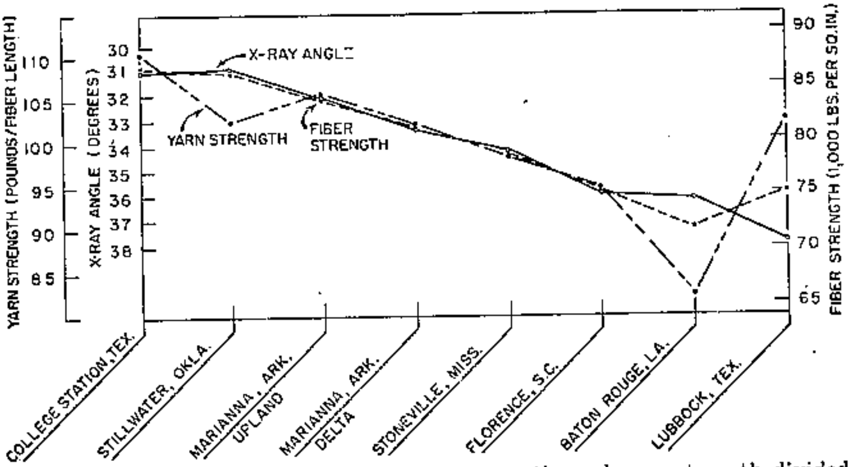

FIGURE 9.—Relation of X-ray angles, fiber strength, and yarn strength divided by fiber length plotted by location. Each plotted point represents the mean of 96 observations including 2 blocks each from 16 varieties for 3 years.

The relationship of X-ray angles, fiber strength, and yarn strength for the regional variety study is shown in figure 9. Fiber strength and X-ray angles are more closely correlated than yarn strength and X-ray angles. There is poor agreement with both fiber and yarn strength at Stillwater, Okla.; Baton Rouge, La.; and Lubbock, Tex. At Stillwater, the fibers were very short, whereas at Baton Rouge some field damage undoubtedly occurred. So far no adequate explanation has been offered for the discrepancy at Lubbock. The cotton at this station was of medium length and strength but spun into a stronger yarn than indicated from the fiber properties.

The relation of fiber structure and strength and yarn strength within a variety is shown in figure 10. There is agreement between X-ray angles and fiber strengths, even though neither are necessarily on the same level from year to year. In 1938 and 1939 the fiber strengths were low, but the skein strengths of 22s yarn were relatively high compared with the X-ray angles. There are no adjustments for either fiber length or strength, which accounts for the apparently poor relationship with skein strength. Although Stoneville 5 is consistently lower in fiber strength for a given X-ray angle than certain other strains [17] the correlation of X-ray angles and fiber strength within this variety is −0.90, which is considered good.

The level of test in the three properties listed varies from year to year, as can be seen in figure 10. The X-ray angles and fiber and yarn strengths were plotted in such way that the means were all on a common level, and a given distance on the scale represents the same percentage of deviation from the mean in each measurement.

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[17] See section on Influence of Species and Varieties, pp. 50 to 56.

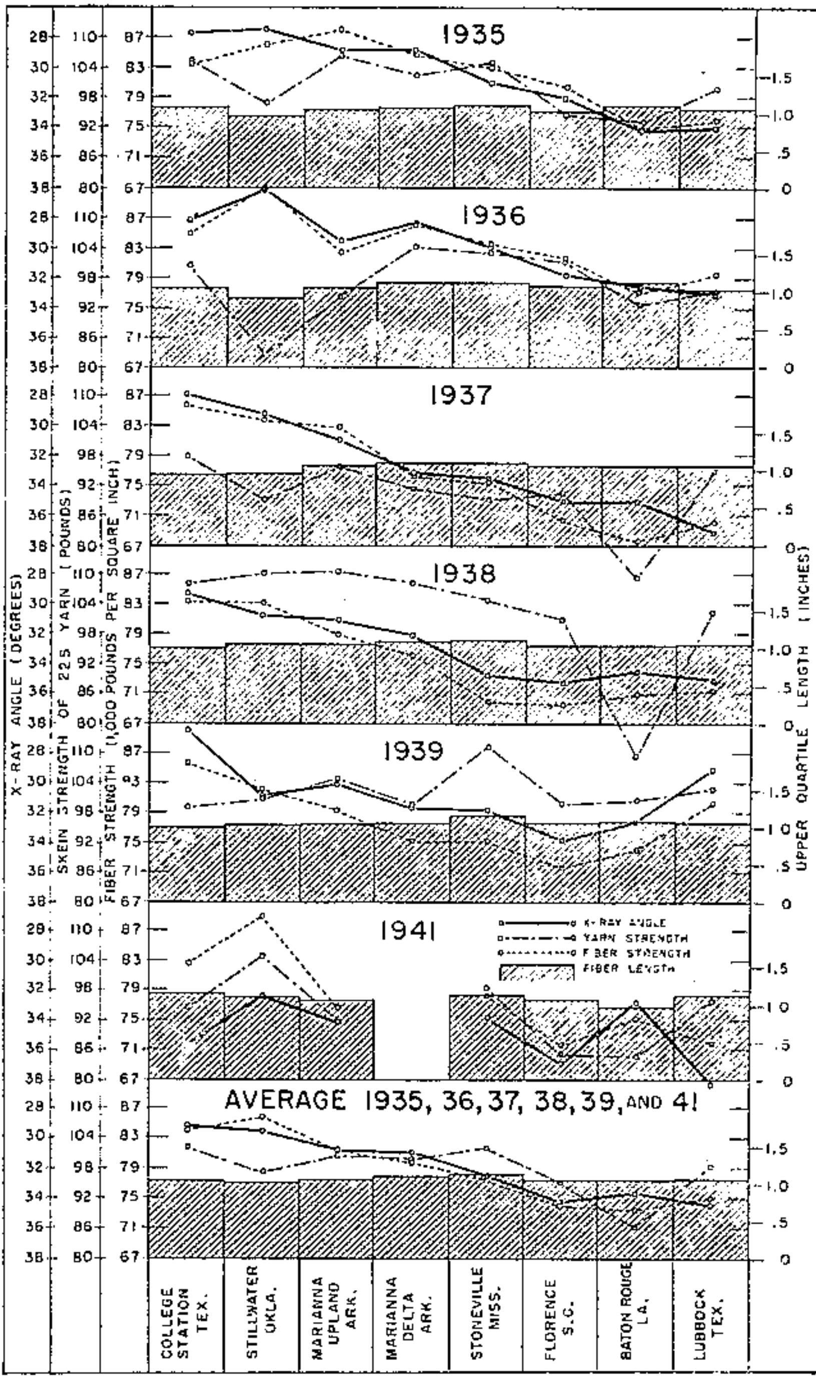


FIGURE 10.—X-ray angles, fiber strength, skein strength, and fiber length for Stoneville 5 cotton grown 5 years (1935–40) at 8 locations and 6 years (1935–41) at 7 of the 8 stations.

As shown elsewhere, both fiber strength and length affect skein strength. There are no adjustments for these factors in figure 10; thus the apparent lack of agreement between fiber properties and skein strengths. The lines representing the X-ray angles and fiber strengths run more or less parallel, but the fiber may be stronger for a given structure for different years, as indicated by the X-ray angles. The same is true of skein strengths, although they are also influenced by fiber length, fineness, and other properties. In 1938 and 1939 fiber strengths were lower, whereas skein strengths were higher than expected for the X-ray angles on the basis of all 6 years.

Differences between varieties and variations due to environment can best be compared in the regional variety study, but the relative effects of fiber length, fineness, structure, and fiber strength on yarn strength are shown better when more than one count is spun from the same cotton. A number of groups of samples were selected where each cotton in a group was spun into the same three counts.

By combining the spinning studies from 1935 through 1942, it was possible to obtain a sufficiently large number of samples in each of these groups for variance analysis. The spinning studies consist of four major groups of cotton spun into (1) 22s, 28s, and 36s; (2) 22s, 28s, and 44s; (3) 22s, 36s, and 50s; and (4) 22s, 44s, and 60s. In all of

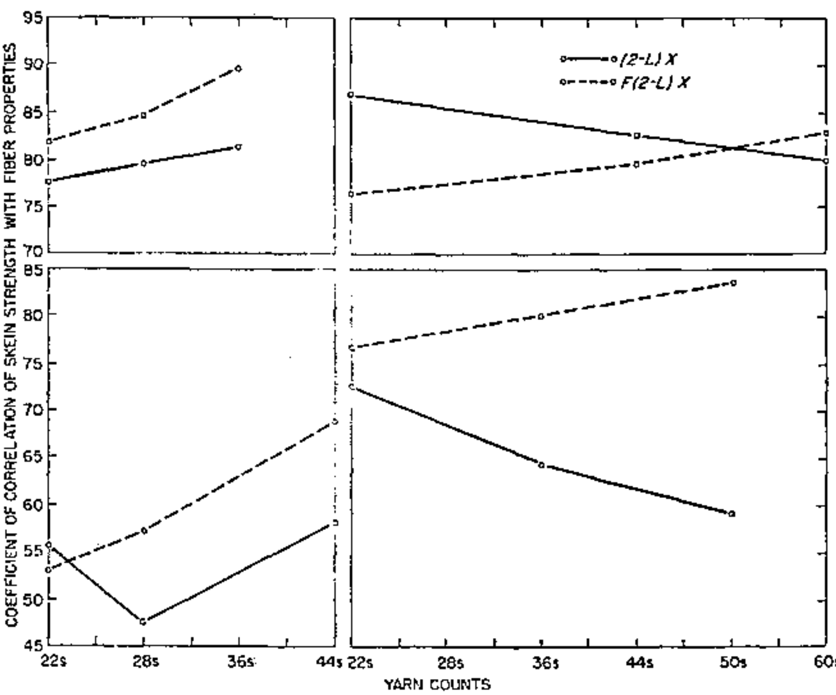


FIGURE 11.—Correlation coefficients or r values by counts when the complement of length $(2-L)$ times X-ray angle (X) as a product $(2-L)X$ or $F(2-L)X$ where F=fineness was correlated with the skein strengths of various counts as shown. Note the decrease in r values at the higher counts when $(2-L)X$ was used and the increase in the same direction with $F(2-L)X$.

these groups the count 22s was common, and in certain others one additional count was common for two groups. In general, the r values became smaller as the counts became greater when the product $(2-L)X$ was used, where L=fiber length and X=X-ray angle (fig. 11). The r value at the level of 22s was greater in certain groups for this factor than when fineness (F) was included in the product $F(2-L)X$. In the latter case, however, the r values became greater as the yarn count increased (fig. 11). This indicates that fineness becomes progressively more important as the count increases, that is, as the yarn becomes finer. This may be expected, since the surface friction on the fibers used at the higher counts is undoubtedly more important than in the coarser counts, where a larger number of the fibers are in the interior of the cross section of the yarn.

It is necessary to use relatively large numbers in order to establish regression equations of value for predicting the skein strength of a cotton from the fiber properties. In each of groups 3 and 4, the numbers were sufficiently large to justify consideration, but the range in fiber length was relatively small within either of these groups. The r values were medium but highly significant, and regression equations derived from them may be used for predicting skein strengths. The correlations due to environmental effects, however, were so poor that the regression equations based on them, as well as on total, may be considered somewhat unreliable. In order to establish an over-all regression equation for predicting the yarn strengths from fiber properties, the 22s of all four groups were combined into a single analysis.

In order to compare the effects of X-ray angles and fiber strengths, when used as products with length and/or fineness, the strength was substituted for the X-ray angles in one set of data. The fiber strength when used with length alone or in conjunction with fineness as a product gave better coefficients of correlation than did the same combination where X-ray angles were substituted for fiber strength. The differences between the two, however, were not great, and either formula when derived from variety comparisons may be used for estimating the yarn strengths of a given sample or variety, but when based on total or environmental effects may not be of interest for predicting skein strengths within a variety.

Discussion and Conclusions

The fiber-structure strength relationship of American upland cottons was examined by covariance for 766 samples, using the Chandler bundle method; and for 905 samples, using the Pressley index method. The coefficient of correlation was greater when the Chandler bundle method was used.

The regression equations, when X-ray angles were correlated with Pressley index, were compared for each of American upland (905 samples), sea-island (161 samples), and American-Egyptian cottons (93 samples). The American upland strains on the average gave the lowest strength, whereas the American-Egyptian cottons gave the greatest strength for a given X-ray angle. The r values and slopes of the regression equation differed significantly from one lot to another, but larger numbers of samples in the sea-island and American-Egyptian groups would be desirable to establish dependable regressions. The sea-island and American-Egyptian cottons on the average were about 2 pounds (Pressley index) higher than the American upland strains for a given X-ray angle.

When the varietal means of individual fiber properties were correlated with the skein strengths of 22s yarn, fiber length and fineness (microgram per inch) gave the highest *r* values, strength third, and X-ray angle least.

For the purposes of this bulletin, it was felt that a rapid, approximate method would be adequate for evaluating the relation of structure, as revealed by the X-ray method, and other fiber properties to spinning performance. Comprehensive multiple correlations for establishing the more precise relationships that may serve as a guide in the cotton research program are being made. Although not completed, these studies appear to confirm the general trends and conclusions here presented. The fiber properties used were length (L), strength (S), fineness as weight per inch (F), and X-ray angle (X). In general, when the product $L \times S$ was correlated with skein strength, the *r* values were greatest at the lower counts and became progressively lower at the higher counts, the 37 samples spun into 22s, 28s, and 36s being the only exceptions. When the product $L \times S/F$ was correlated with skein strength, the *r* values were least at the lower counts and became progressively larger at the higher counts.

These results indicate that fiber fineness, as well as length, is of progressively greater importance in the finer yarns. The skein strength of the coarser yarns appears to be dominated by the effects of fiber length and strength.

The structure of the fiber, as shown by X-ray angle, may be substituted for the fiber strength in making progeny selections. Slightly lower but not necessarily significantly different *r* values were usually obtained when the X-ray angles were used instead of the fiber strength in the products of length and/or fineness. This may be due to one or both of two causes: (1) Field damage affects the fiber and yarn strengths considerably but has little or no effect on the X-ray angles; (2) certain varieties or strains of cotton are stronger than others with similar X-ray angles.

Care must be exercised in interpreting X-ray data in terms of quality, because of variation in strength-structure relationship from one group of cottons to another.

It may be concluded that some 80 to 90 percent of the variations in yarn strength dependent on varietal characteristics can be accounted for by the fiber properties included in this study. Correlation coefficients of 0.95 and 0.94 were obtained for the varietal effect where the product of length times strength ($L \times S$), and length divided by X-ray angle ($L \div X$), respectively, were correlated with the weighted skein strengths of 22s yarn. Lower *r* values may be expected for total and environmental effect when covariance is applied to the data.

The X-ray method can be used successfully in cotton-breeding studies and might be preferred to strength methods for samples that have sustained differential field damage sufficient to impair the fiber strengths.

INFLUENCE OF GROWING CONDITIONS

By Thomas Kerr and Earl E. Berkley

Statement of Problem

It is well known that the fiber properties of cotton vary with the environmental conditions under which the plants are grown. The effects of environmental fluctuations on the strength and spiral structure of cotton fibers are discussed herein, particularly from the standpoint of extent of variations and causal factors.

Results

The variations in X-ray angles and fiber strength induced by environmental factors for the regional variety study may be seen in figure 12. As shown by the variance analysis in the preceding section

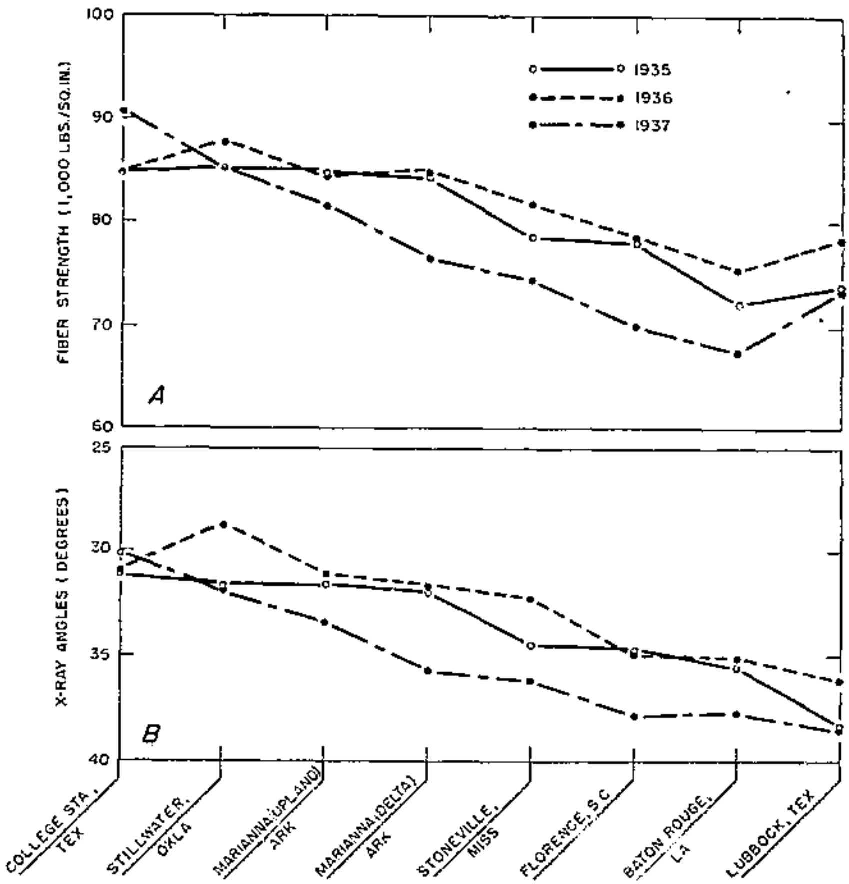


Figure 12.—*A*, Fiber strength (Chandler bundle method), and *B*, structure as shown by X-ray angles, for duplicates of 16 varieties of cotton plotted by location of growth for 3 years. Each plotted point represents 32 observations.

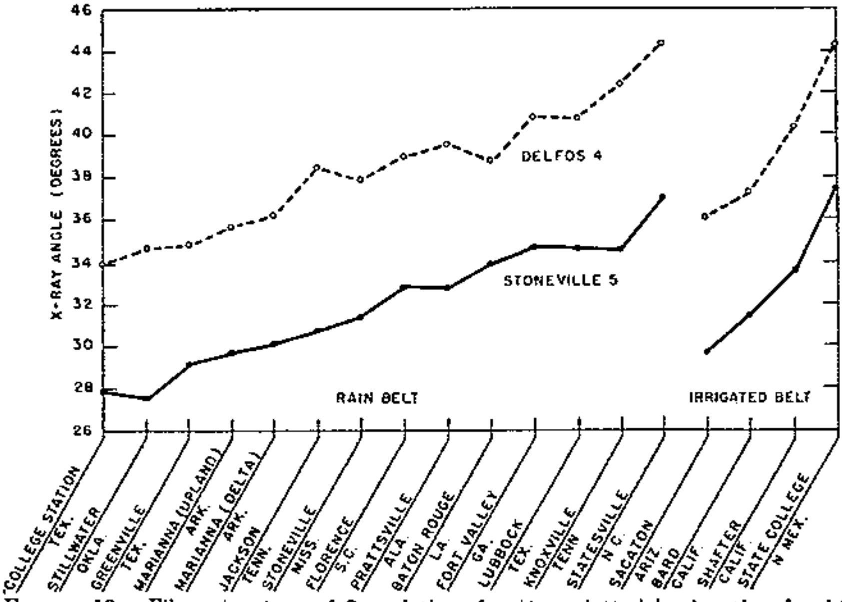


FIGURE 13.—Fiber structure of 2 varieties of cotton plotted by location for 14 stations in the rain belt and for 4 in the irrigated region; averages for 1935-37 crops.

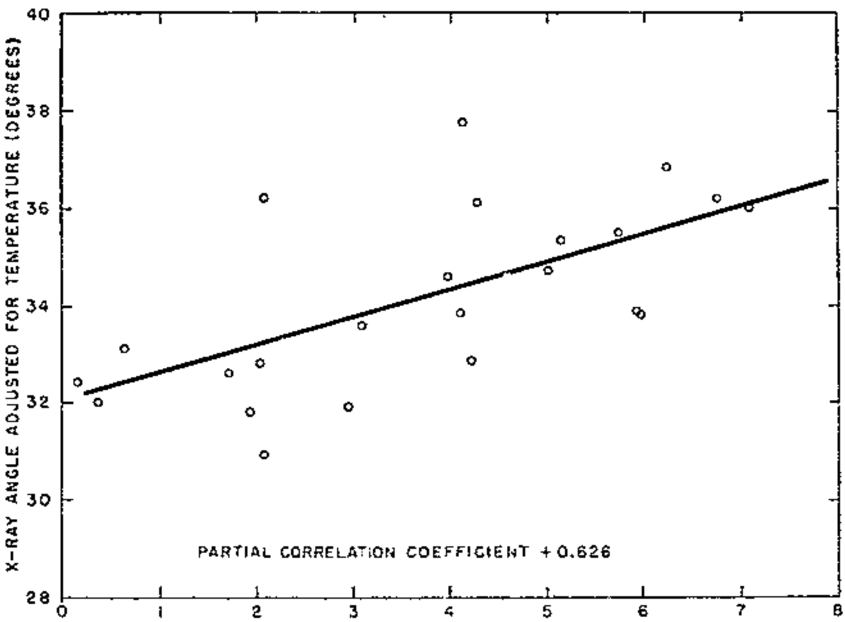


FIGURE 14.—Relation of rainfall to crystalline cellulose orientation in cotton fibers. Each plotted point represents 32 observations on 16 varieties of cotton. Adjustments for temperature were obtained from the relationship shown in figure 15. The rainfall was accumulated over a period of 45 days during the time fibers were being produced.

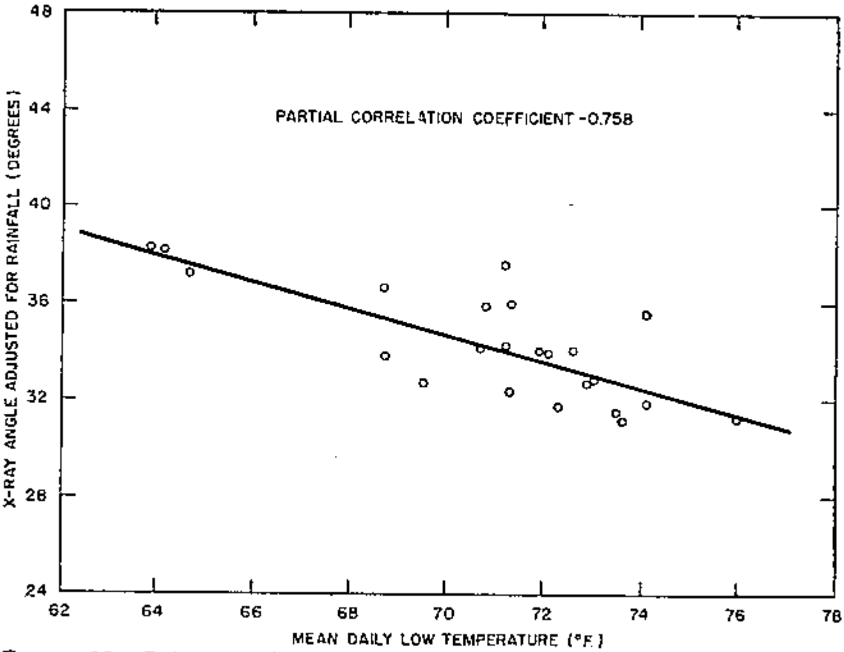


FIGURE 15.—Relation of daily low temperatures to fiber structure. Each plotted point represents 32 observations. The adjustments for rainfall were taken from the relationship shown in figure 14. The temperature is the low mean for the 45 days when fibers were being produced.

(p. 23), the effects of location and year on the fiber structure and strength of these cottons were numerically greater than the varietal effects. It may be seen further in figure 13 that when individual varieties are examined at a greater number of locations, including the irrigated region, similar differences were found. In general, different varieties respond similarly at all locations.

RAINFALL AND TEMPERATURE

An examination of weather records indicated that fibers with high strength and small X-ray angles were produced at locations with relatively high temperature and low rainfall, e. g., College Station, Tex. A rough estimate of the rainfall during the period of development of the fibers (illustrated in fig. 14) was obtained by adding the daily rainfall for a period of 45 days during the period when most of the fibers were being produced. Rains in excess of 1 inch and no more than 3 inches in 24 hours were corrected for runoff by reducing them 15 percent and when more than 3 inches, by reducing them 50 percent. Figure 14 for rainfall and figure 15 for temperature show the partial correlation coefficients when both rainfall and mean daily low temperatures were correlated with the average X-ray angles for all 16 varieties at each of 7 locations for 1935 and 8 locations for 1936 and 1937.[18]

[18] The missing point was from Marianna (upland), Ark., in 1935, where no weather records were kept.

Low rainfall would mean low soil moisture and consequently low available water for the plant. High temperatures, particularly during the hot part of the day, would result in high transpiration, or high water loss, and likewise low available water for the plant. Therefore, it is not clear whether the effects of rainfall and temperature are independent factors. Furthermore, the soils at the various locations differ greatly and it is not clear how much this may affect the moisture relationships.

ADDITIONAL EXPERIMENTS IN THE RAIN BELT

At the time these data were being studied, a set of experiments known as the "crop weather study" were being conducted by Charles F. Sarle, assisted by A. L. Finkner, Production and Marketing Administration. He furnished the authors representative samples that made it possible to compare the effect on the spiral structure of variety, location, planting date, fertilizer treatments, and time of flowering. Time of flowering refers to the period of fiber development. The early bolls matured during hot summer weather, whereas the late fruits developed in autumn, which was characterized in some locations by cool nights and at others by considerable drought. Table 10 contains the X-ray angles for four varieties, three locations, two dates of planting, two levels of fertilizer application, and four dates of flowering.

Analysis of a part of the data (table 11) indicates that among the main effects, flowering date and variety were highly significant, whereas fertilizer treatment was of interest and perhaps would have been significant if pronounced deficiencies in essential elements had existed. The interaction of dates of planting and flowering was also highly significant. These data further emphasize the importance of temperature and moisture in determining fiber properties and indicate that the fruiting load also may increase stress.

TABLE 10.—*X-ray angles by variety and location for the crop weather study, 1940 crop*

Place and time of planting	Fertilizer treatment	Date tagged	Varieties: Stoneville 2B	Varieties: Oklahoma Triumph	Varieties: Dixie Triumph	Varieties: Shafter Acala
Florence, S. C.:			*Degrees*	*Degrees*	*Degrees*	*Degrees*
Normal	High	July 7	30.1	---	---	---
	do	do	30.2	---	---	---
	Low	do	31.2	---	---	---
	do	do	30.2	---	---	---
	High	July 14	35.0	41.3	33.6	42.0
	do	do	35.0	37.2	33.7	42.2
	Low	do	34.0	42.0	35.9	41.6
	do	do	35.2	37.6	---	43.0
	High	do	---	42.5		
Late	High	do	34.6	---	37.6	41.2
	do	do	35.4	---	37.4	42.3
	Low	do	35.8	41.0	36.9	43.7
	do	do	35.2	42.4	35.3	43.7

TABLE 10.—*X-ray angles by variety and location for the crop weather study, 1940 crop*—Continued

Place and time of planting	Fertilizer treatment	Date tagged	Varieties: Stoneville 2B	Varieties: Oklahoma Triumph	Varieties: Dixie Triumph	Varieties: Shafter Acala
			Degrees	*Degrees*	*Degrees*	*Degrees*
Florence, S. C.—Continued						
Normal	High	July 21	32.4	38.4	34.0	33.4
	do	do	31.6	36.2	33.9	40.0
	Low	do	32.6	37.9	35.0	40.9
	do	do	32.4	37.4	35.3	42.1
Late	High	do	30.2	38.8	41.0	38.0
	do	do	31.7	35.8	32.2	39.2
	Low	do	37.3	36.4	33.2	40.1
	do	do	31.0	36.2	34.7	38.8
	High	Aug. 2	36.9	40.6	36.8	44.0
	do	do	35.2	40.0	35.8	42.1
	Low	do	34.7	39.4	35.4	42.2
	do	do	34.7	42.0	36.1	43.2
Experiment, Ga.:						
Normal	High	July 29	33.4	------	------	------
	do	do	35.2	------	------	------
	Low	do	35.7	------	------	------
	do	do	34.4	------	------	------
	High	Aug. 9	32.6	38.2	35.3	41.4
	do	do	33.2	39.4	34.2	37.7
	Low	do	31.0	------	------	------
	do	do	32.2	------	------	------
Late	High	do	31.8	40.9	34.0	39.9
	do	do	33.3	39.4	33.9	39.8
	Low	do	32.3	------	------	------
	do	do	31.4	------	------	------
Normal	High	Aug. 20	30.9	40.2	33.4	40.2
	do	do	33.2	34.2	------	36.0
	Low	do	31.0	------	------	------
	do	do	34.4	------	------	------
Late	High	do	32.6	35.3	30.1	37.2
	do	do	29.6	38.0	------	36.8
	Low	do	29.8	------	------	------
	do	do	29.0	------	------	------
	High	Aug. 26	30.0	35.0	29.3	34.4
	do	do	29.8	38.4	31.3	37.0
	Low	do	27.4	------	------	------
	do	do	29.2	------	------	------
	High	Sept. 6	------	40.2	33.0	39.6
	do	do	------	38.0	------	36.6
	do	Sept. 9	31.8	------	------	------
	do	do	33.0	------	------	------
	Low	do	32.0	------	------	------
	do	do	30.2	------	------	------
Stoneville, Miss.:						
Normal	High	July 18	34.6	35.6	36.6	39.6
	do	do	34.6	40.4	37.0	42.0
	Low	do	37.5	------	------	------
	do	do	39.5	------	------	------
	High	July 30	34.6	38.8	37.0	40.8
	do	do	34.8	38.4	36.0	40.8
	Low	do	35.9	------	------	------
	do	do	35.2	------	------	------

TABLE 10.—*X-ray angles by variety and location for the crop weather study, 1940 crop*—Continued

Place and time of planting	Fertilizer treatment	Date tagged	Varieties			
			Stoneville 2B	Oklahoma Triumph	Dixie Triumph	Shafter Acala
			Degrees	*Degrees*	*Degrees*	*Degrees*
Stoneville, Miss.—Con.						
Late	High	July 30	35.2			
	do	do	35.1			
	Low	do	34.6			
	do	do	35.7			
Normal	High	Aug. 9	34.4	38.6	35.6	39.6
	do	do	31.8	38.6	35.4	40.4
	Low	do	34.6			
	do	do	32.4			
Late	High	do	35.4	40.7	36.0	39.9
	do	do	35.2	38.5	36.2	40.9
	Low	do	35.4			
	do	do	33.5			
	High	Aug. 16	33.4	37.6	35.1	38.4
	do	do	35.4	37.8	34.9	39.8
	Low	do	34.0			
	do	do	33.2			
Marianna, Ark.:						
Normal	High	Aug. 3	35.1			
	do	do	35.2			
	Low	do	35.5			
	do	do	36.6			
	High	Aug. 8	35.6	40.4	36.4	40.2
	do	do	34.9	38.8	37.2	40.9
	Low	do	36.6			
	do	do	34.6			
Late	High	do		40.8	38.3	
	do	Aug. 18			35.5	
Normal	High	Aug. 19		37.4	35.6	40.9
	do	do		35.4		
Late	High	do	33.2	39.6		
Lawton, Okla.:	*Spacing*[1]					
Normal	Thick	July 31	33.5			
	do	do	34.4			
	Thin	do	33.4			
Late	Thin	Aug. 12	30.7			
Normal	Thick	do	32.6			
Late	do	do	32.8			
	do	do	32.2			
Normal	Thin	do	32.6			
Late	Thick	Aug. 22	31.8			
	do	do	31.7			
Normal	Thin	do	32.4			
	Thick	do	32.6			
Late	Thick	Aug. 29	34.8			
	Thin	do	34.9			

[1] Spacing in lieu of fertilizer treatment was superimposed on the experimental design.

TABLE 11.—*Variance analysis of X-ray angles from the crop weather studies at Florence, S. C., 1940 crop* [1]

Variance	Degrees of freedom	Mean square
Blocks	1	1. 85
Date of planting	1	1. 62
Date of tagging	1	[2] 278. 48
Tagging × planting	1	[2] 43. 93
Fertilizers	1	[3] 15. 26
Fertilizers × planting	1	2. 64
Fertilizers × tagging	1	3. 51
Varieties	3	[2] 400. 07
Variety × planting	3	2. 25
Variety × tagging	3	3. 44
Variety × fertilizer	3	4. 17
Higher order interactions	13	2. 50
Experimental error	28	2. 99
Between duplicate samples	61	. 47
Total	121	14. 24

[1] The samples represent duplicates of 4 varieties of cotton with 2 dates of planting, 2 rates of fertilizer treatment, and 2 taggings with an interval of 2 weeks. Values for 3 plots were missing, and the values observed in the other plots in each case were substituted, which accounts for the loss of 6 degrees of freedom.
[2] Highly significant, odds of 99:1.
[3] Significant, odds of 19:1.

It is difficult, however, to correlate the X-ray angles with either the temperature or the rainfall, although it is obvious from figure 16 that low rainfall and, in some cases, high temperature existed during the period when the smaller X-ray angles were produced. The X-ray angles from samples from Florence, S. C., were greatest in the samples produced during the wet period and least during the relatively dry periods. At Experiment, Ga., Stoneville, Miss., and Lawton, Okla., the weather became progressively drier; however, at Experiment and Lawton the temperature was apparently low enough late in the season to reduce the stress on the plants, as indicated by the larger angles.

In another experiment, the usual growing season was extended by planting two varieties of cotton in the greenhouse and by transplanting them to the field as soon as the weather permitted, both at Raleigh and Statesville, N. C., in 1940. Duplicate blocks of the same varieties also were planted at the usual time and a third group 3 weeks later. Blossoms opened from June 19 until late in August. Flowers were tagged at frequent intervals and the bolls collected and studied. The X-ray angles varied considerably from one part of the season to another (fig. 17), and in these tests the combination of moisture and temperature appeared to be more effective than either alone. When it was hot and dry the angles were very small; when it was cool and wet they were large; but late in the season the angles were small again despite the cool weather. There was little or no rainfall in the latter part of the season, however, and the plants were badly stressed, as determined by the extensive wilting, despite lower fall temperatures.

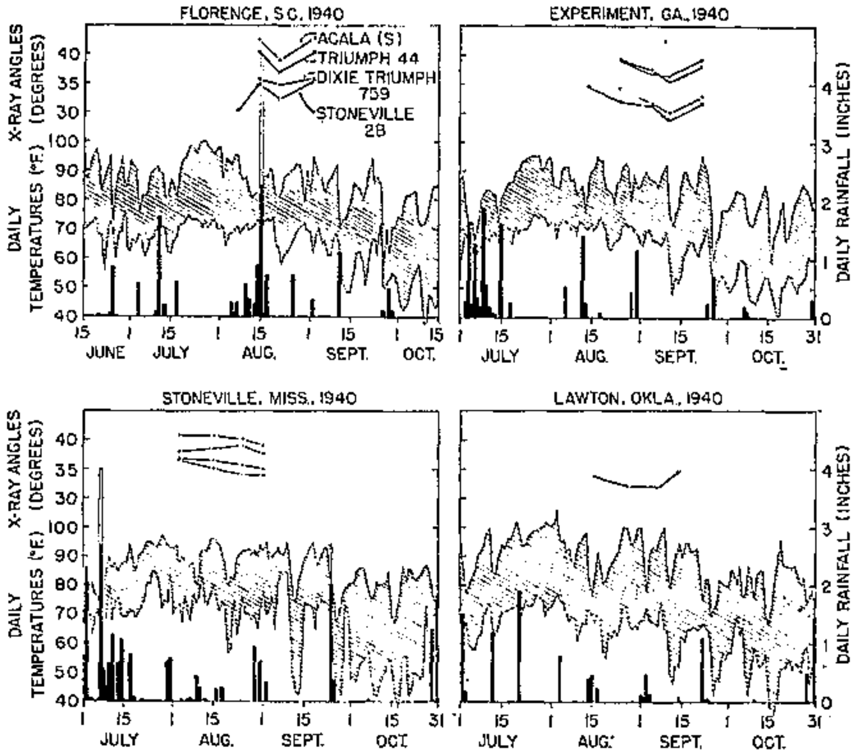


FIGURE 16.—X-ray angles and weather data from four locations plotted by days during the summer of 1940.

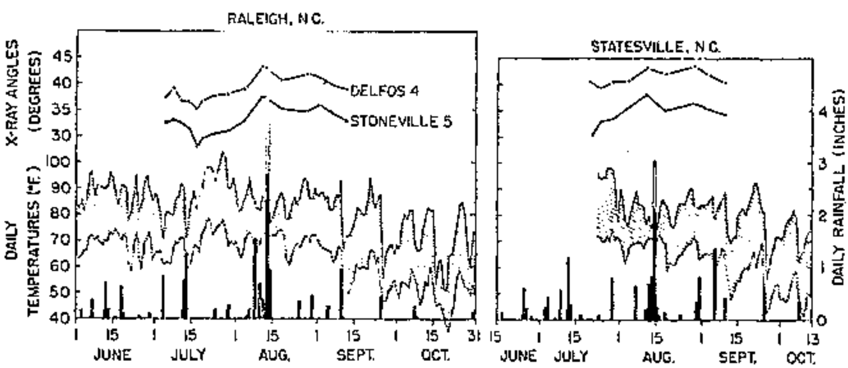


FIGURE 17.—X-ray angles and weather data from two locations plotted by days during the summer of 1940. As in figure 16, the X-ray angles were greatest during the wet period and least during the dry, hot period in July and at the end of the season, when there was little moisture left in the soil.

During the progress of this experiment it was observed that the soil above a terrace that extended across the blocks was relatively moist compared with the rest of the field. Bolls collected from this area were kept separate and found to be different from those from the drier area (table 12). At certain periods the X-ray angles were smaller from the moist plots than from the dry. This was somewhat confusing until similar data were obtained under irrigation.

TABLE 12.—*X-ray angles by dates of tagging for the transplants and early and late planting for 2 varieties of cotton grown at Raleigh, N. C., 1940 crop*

Date tagged	Stoneville 5: Moisture level: Dry	Stoneville 5: Moisture level: Wet	Stoneville 5: Mean	Delfos (Missdel) 4: Moisture level: Dry	Delfos (Missdel) 4: Moisture level: Wet	Delfos (Missdel) 4: Mean
	Degrees	*Degrees*	*Degrees*	*Degrees*	*Degrees*	*Degrees*
Transplanted from Greenhouse						
June 19	----	----	[1] 32.6	----	----	[1] 37.3
June 22	32.2	34.2	33.2	----	----	[1] 39.1
June 23	----	----	----	37.1	35.4	36.2
June 25	31.8	33.4	32.6	36.8	36.8	36.8
June 28	33.3	29.7	31.5	35.4	38.0	36.7
July 1	25.6	30.5	28.0	36.0	34.4	35.2
July 3	29.7	29.6	29.6	35.6	37.8	36.7
July 8	30.0	31.3	30.6	39.0	36.6	37.8
July 13	31.4	30.8	31.1	37.8	38.0	37.9
July 19	32.6	32.8	32.7	35.4	38.9	37.2
Mean	30.8	31.5	31.3	36.6	37.0	37.1
Normal Planting						
July 19	31.8	34.8	33.3	41.0	40.8	40.9
July 26	37.1	38.3	37.7	43.2	----	43.2
Aug. 2	34.4	36.1	35.2	39.8	41.4	40.6
Mean	34.4	36.4	35.4	41.3	41.1	41.6
Late Planting						
Aug. 2	33.9	36.7	35.3	40.1	41.8	41.0
Aug. 12	33.2	36.5	34.8	40.5	43.2	41.8
Aug. 17	35.6	36.3	36.0	41.5	40.8	41.2
Aug. 21	34.4	35.2	34.8	40.4	39.6	40.0
Aug. 27	33.6	32.5	33.0	39.0	----	39.0
Mean	34.1	35.4	34.8	40.3	41.4	40.6
Over-all mean	32.5	33.7	33.1	38.7	38.8	38.8

[1] Not designated if moisture levels were dry or wet.

IRRIGATION STUDIES

Two or more varieties of cotton were grown under variable irrigation at two stations—State College, N. Mex., and Sacaton, Ariz.—which varied widely in altitude and, therefore, air temperature. The X-ray angles from these studies are shown in table 13. For the same varieties, irrespective of irrigation, the X-ray angles were smaller at Sacaton than at State College. At State College in 1939 and 1940 the X-ray angles were progressively smaller as irrigation became lighter. The same was true at Sacaton in the early part of the season of 1940. Toward the end of the summer, however, the angles became smaller in the highly irrigated plots and in certain instances were less than those from the so-called stressed plots for the same date of tagging. The experiments were repeated in 1941 with the same results. It was observed for the most part that in the heavily irrigated and to some extent in the normal plots, the plants were much larger than in the stressed plots (tables 14 and 15). At Sacaton where high temperatures prevailed, the larger plants wilted badly, whereas the smaller plants on the lightly irrigated plots did not. At State College, with an elevation of 3,800 feet above sea level, the plants were not subject to such high temperatures, so that the water loss was not excessive; therefore the lightly irrigated plots continued to produce cotton with better structure and strength than the normal or heavily irrigated plants.

TABLE 13.—*X-ray angles from cottons grown under various quantities of irrigation at Sacaton, Ariz., where high temperatures prevail, and at State College, N. Mex., where relatively cool nights are common*

SACATON, ARIZ.

Variety	Planting	Date tagged	X-ray angle under— Heavy irrigation	Normal irrigation	Light irrigation
		1940	*Degrees*	*Degrees*	*Degrees*
Acala (S)	Early	July 8	--------	37.7	33.6
		Aug. 1	--------	35.0	34.4
		Aug. 27	--------	39.8	40.4
	Late	Aug. 27	--------	39.3	40.4
		Sept. 18	--------	39.8	41.3
Stoneville 5	Early	July 8	--------	29.3	28.8
		Aug. 1	--------	27.4	25.4
		Aug. 27	--------	30.5	32.0
	Late	Aug. 27	--------	33.4	31.0
		Sept. 18	--------	32.6	31.5

TABLE 13.—*X-ray angles from cottons grown under various quantities of irrigation at Sacaton, Ariz., where high temperatures prevail, and at State College, N. Mex., where relatively cool nights are common*—Continued

SACATON, ARIZ.—Continued

Variety	Planting	Date tagged	X-ray angle under— Heavy irrigation	Normal irrigation	Light irrigation
		1940	*Degrees*	*Degrees*	*Degrees*
Delfos (Missdel) 4	Early	July 8	--------	39.2	35.2
		Aug. 1	--------	35.4	33.6
		Aug. 27	--------	37.8	37.8
	Late	Aug. 27	--------	39.9	40.2
		Sept. 18	--------	37.8	40.2
		1941			
Acala (S)		July 15	37.2	37.4	36.0
		July 30	38.3	34.8	35.6
		Aug. 15	36.8	35.2	34.4
		Aug. 30	36.5	34.9	34.0
		Sept. 15	36.5	36.3	39.2
Stoneville 5		July 15	29.0	29.1	25.8
		July 30	29.0	29.7	28.6
		Aug. 15	26.3	26.2	23.6
		Aug. 30	25.4	25.4	24.8
		Sept. 15	29.4	30.0	29.0
STATE COLLEGE, N. MEX.					
Acala (S)		1939 [1]	38.0	34.6	33.5
		1939 [1]	37.0	36.0	31.6
Do		1940	35.7	34.4	30.7
		1941			
Acala 1517		July 14	35.4	34.5	32.8
		July 29	34.4	34.2	30.2
		Aug. 13	36.0	34.9	32.7
		Aug. 28	36.4	35.6	35.6
		Sept. 12	30.0	32.1	28.9
Stoneville 5		July 14	40.8	39.0	36.2
		July 24	39.1	38.0	34.6
		Aug. 13	37.4	35.7	35.4
		Aug. 28	37.8	38.8	36.4
		Sept. 12	37.4	40.3	--------

[1] Duplicate lots taken from spinning samples.

TABLE 14.—*Average height of plants for well irrigated and lightly irrigated (stressed) plots for three varieties of cotton* [1]

Date planted and variety	Date plants measured	Heights of plants under— Normal irrigation	Light irrigation
		Centimeters	*Centimeters*
Apr. 12:			
Shafter Acala	Aug. 7	62.3	56.8
	Sept. 4	67.3	57.2
Stoneville 5	Aug. 7	61.6	48.1
	Sept. 4	68.2	49.4
Delfos (Missdel) 4	Aug. 7	76.0	77.2
	Sept. 4	81.2	77.5
May 1:			
Shafter Acala	Aug. 7	85.0	102.3
	Sept. 4	93.2	103.2
Stoneville 5	Aug. 7	80.2	68.3
	Sept. 4	85.1	70.4
Delfos (Missdel) 4	Aug. 7	86.3	80.6
	Sept. 4	93.1	80.4

[1] Data taken from King's Data Book on the samples grown for the effects of irrigation on cellulose alinement, 1940 crop.

TABLE 15.—*Number of leaves per plant for 2 varieties of cotton and 3 rates of irrigation, Sacaton, Ariz., 1941 crop*

Variety	Date counted	Leaves per plant under— Heavy irrigation	Normal irrigation	Light irrigation
		Number	*Number*	*Number*
Acala Shafter	July 25	69.5	62.9	73.8
Do	Aug. 26	123.9	95.3	85.0
Stoneville 5	July 25	77.7	95.6	113.9
Do	Aug. 26	151.6	141.2	143.4

STRESS ON PLANTS

Stress during the early stages of vegetative growth affects the size of the plants. The extent of water loss at the time the bolls are maturing is in turn affected by the leaf area exposed. In the experiments at Sacaton in 1940, the same quantity of water was supplied all plots on September 11, the date of the last irrigation. From that time until the end of the season, the larger plants, transpiring more water, would be under greater stress, and it is not surprising to find that these plants had fiber with smaller angles. In 1941, rain late in September produced a similar condition.

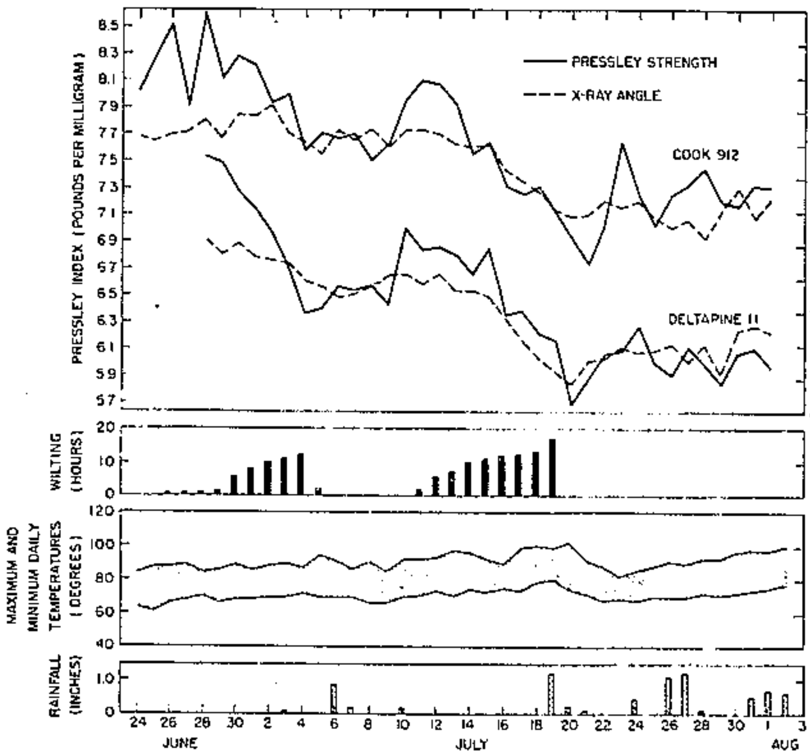


FIGURE 18.—X-ray angles and Pressley indices, daily temperatures, rainfall, and degree of wilting for two plantings each of two varieties of cotton grown at Raleigh, N. C., in 1942.

In view of these observations, an attempt was made to measure the stress by observing the extent of wilting and by measuring the variations in boll size with auxometers during the period of boll growth and maturation at Raleigh, N. C., in 1942. Daily records were kept and fibers from bolls initiated each day during the flowering season were studied. Figure 18 shows in graph form the X-ray angles, fiber strengths, daily weather data, and extent of wilting for two varieties of cotton, including two plantings each. It will be observed that the X-ray angles became smaller and fiber strength greater as the wilting became more pronounced. The auxometer measurements also indicate that stress existed in the plants. The bolls varied in size as they lost or gained turgidity. In general, they became smaller during the hot part of the day and regained size during the night.

In the greenhouse at Beltsville, Md., four cotton plants were grown continuously for 2 years. Adequate water for good growth was supplied at all times, but the summer temperatures in the greenhouse were much higher than winter temperatures. The difference in the winter and summer stress conditions is reflected in the X-ray angles from fibers maturing during these periods (table 16).

TABLE 16.—*X-ray angles, representing alternate summer and winter, from 4 cotton plants grown continuously without transplanting, in a greenhouse at Beltsville, Md.*

Variety	Summer, 1943	Winter, 1943–44	Summer, 1944	Winter, 1944–45
	Degrees	*Degrees*	*Degrees*	*Degrees*
De Ridder	30. 6	44. 6	35. 1	49. 4
Stoneville	28. 8	(1)	27. 6	44. 0
Cook	32. 2	43. 3	34. 0	42. 7
Delfos	37. 4	49. 8	39. 7	48. 0

[1] No data.

DISCUSSION

In the data presented, it may be seen that the spiral structure and the fiber strength were both affected similarly by environmental conditions. In the course of this work it became apparent that the chief environmental factor influencing fiber strength appears to be the water stress of the plant.

Stress in the plant is equivalent to lack of turgor. The turgor of the plant cells has been defined by the equation, turgor=osmotic pressure−diffusion-pressure deficit. A discussion of the water relations in plant cells is given by Ursprung (*34*) and by Meyer (*19*). If high stress is correlated with variations in turgor, it would seem advisable to measure the turgor and show this correlation. Unfortunately, all attempts to measure turgor accurately have failed, and, therefore, the term "stress" in a more general sense has been used. Working on this thesis, however, it has been possible to explain in general most of the variations in strength that have been found.

The turgor of the cotton plant may be affected by the quantity of available water (i. e., soil moisture) and also by the rate of water loss. Rainfall gives only a rough estimate of the quantity of available water, and nothing about water loss. Transpiration from the plant would be influenced chiefly by the temperature and relative humidity (or rather the vapor pressure of the air). These factors were measured, but unfortunately they tell only part of the story. The size of the plant and particularly the leaf surface undergoing transpiration (including the unknown root-shoot ratio) are also factors to be taken into account. This was apparent in the late tagging of the irrigated cotton at Sacaton, Ariz., and to a lesser degree in the samples from the plants in the wet plots at Raleigh, N. C., in 1940. Plants growing at a high water level develop low osmotic pressures in their cells and wilt more readily. All these factors must be taken into consideration in working on the problems of water stress.

In addition, the question arises: When, during boll development, does water stress affect the spiral structure and consequently the strength? From the standpoint of development, it seems logical to assume that water stress should affect the structure during the period of secondary deposition, i. e., from 16 to 40 days after flowering.

Fruits are set at different dates over the season, however, so that the total crop is affected by the weather during a longer period. In general, the seasons may be either dry or wet. On the other hand, particularly in the eastern part of the Cotton Belt, the weather may change abruptly during the period of boll development. These abrupt changes have shown quite clearly that the spiral structure is affected by the summation of the stress during the period of secondary deposition (fig. 18).

In the data collected at Raleigh in 1942 there was a period of severe wilting (July 15–22) relieved by cloudy weather and light rains when no stress was evident (but only temporary relief occurred, July 23–26), followed by increasingly severe stress conditions until August 4. After this date, there came a period of heavy rains. The break on August 4 was an extreme change. Nevertheless, bolls beginning secondary wall deposition in the severe drought (July 28–August 4) showed increasingly larger angles as the number of days during which they underwent deposition under stress conditions diminished. This can only mean that the final X-ray angles are a summation of the spiral structure in the various growth rings; and that each day's depositions are influenced by the stress conditions present at that time. During the early part of secondary thickening, the quantity of cellulose deposited is more than during the later stages of maturation (*5*); consequently the summation of stress during the period of secondary wall deposition cannot be determined accurately by adding the stress for the total period of boll development.

The problem of estimating stress was exceedingly difficult. In view of the unexpected results on the late taggings of cotton grown under irrigated conditions it became obvious that if any significant measure of turgor was to be obtained it would be necessary to go to the plant, rather than to attempt to evaluate factors in the environment. Direct measurements of the osmotic pressure and the diffusion-pressure deficit were taken, so that the turgor might be calculated, using the equation turgor=osmotic pressure−diffusion-pressure deficit (*15*). In calculating turgor in growing cotton bolls this equation was not valid, since the values for the diffusion-pressure deficit were found to exceed the osmotic pressure in bolls more than 24 days old, even when the bolls were obviously turgid.

Auxometer measurements (*2*) of the growing bolls also were made, and these showed quite clearly the degree of shrinkage in the growing bolls under different stress conditions. The quantity of shrinkage, however, varied with age of boll and exposure to sunlight. Furthermore, an auxometer occasionally broke down at a critical period, as the sensitivity of the instrument is such that it will not always withstand the rugged weather conditions found in the field. In addition, it was not practicable to operate a sufficient number of auxometers to obtain enough data to correlate accurately with the X-ray angles.

In the absence of a general method for measuring turgor, the extent of wilting gave the best results as a measure of stress conditions. Incipient wilting represents the absence of turgor, whereas severe wilting is accompanied by plasmolysis. Records on wilting gave no idea of the extent of stress preceding this stage, but when wilting occurred it was easily measured and the number of hours in the wilted condition gave an estimate of the stress on the boll. Stress may be present even though wilting does not occur, but this has not been measured.

In view of the fact that the spiral structure is highly influenced by stress conditions that cannot be measured accurately, it is difficult to determine whether other environmental factors also affect the spiral structure. Thus, it is apparent that changes in temperature (fig. 15) influence the X-ray angles. Although this influence appears chiefly in the form of water loss, it is believed that temperature alone may have an independent effect. The possible influence of soil fertility on fiber strength has also entered into the picture, but from the data presented here, no significant conclusions on this point can be drawn. A difference in fertilizer level obtained by using the crop weather data of 1940 gave values approaching significance, whereas values of data on variety and dates of tagging were highly significant.

Water stress influences fiber properties other than spiral structure. Lint length is reduced, weight fineness may be increased, and yield may be lowered by lack of turgor within the plant. Bonnen and others (7) have shown that length and strength are essentially compensatory factors tending to make yarn strength constant within a given variety. When this correlation exists, it is apparently caused by the influence of stress conditions during fiber development.

When the situation is analyzed more closely it may be seen that fiber length is affected by stress during the early stages of boll development, i. e., during the period of fiber enlargement (10 to 16 days after flowering) (*31*), while strength varies with the turgor during the period of boll maturation (16 to 40 days after flowering). It is possible that the weather may change after the fibers have reached their mature length and that the fibers may develop under two different sets of environmental conditions. Such a change is not common, although it is possible to produce a favorable combination of high lint length and high strength under irrigation. From the growers' standpoint, however, increased strength through stress conditions usually means decreased yields. Therefore, further advances in high-strength cotton must come by means of plant breeding and not through cultural practices.

Conclusions

Cotton fibers grown at different locations, in different seasons, and in different parts of the same season at the same location, and under widely different levels of irrigation at the same and different locations, were examined for variation in cell-wall structure and tensile strength. As a result of the studies on the influence of growing conditions on the fiber properties of cotton, the following conclusions are possible:

The environmentally induced variations in fiber properties and spinning quality of cotton are frequently pronounced and may be of considerable importance.

Environmental conditions that affect the water relations in the plant modify the fiber structure and strength of the cotton.

Cottons grown under stress usually produce strong fiber with relatively small X-ray angles.

The turgor of the plant during the period of deposition of the cellulose of the secondary thickening appears to be the controlling factor in the environmentally induced strength and structure of the fiber.

The turgor of the plant may be affected by a low water level in the soil, by high temperatures combined with low relative humidity, or by any factor that creates a greater water loss from the leaves than the supply or movement of water in the plant.

Plants grown under low irrigation may show less stress during the latter part of the season than other plants grown under high irrigation, owing to the enormous leaf surface on the latter.

Since the environmental conditions associated with high strength usually reduce the yield and staple length, it is advisable to obtain strong cottons by breeding rather than by cultural practices.

INFLUENCE OF SPECIES AND VARIETIES

By Earl E. Berkley and C. J. King

General Background

Maintenance of quality and the development of improved varieties and strains are necessary if the United States is to maintain or improve its position in the cotton trade. The cotton breeder is limited by the measurements or the tools he has at his disposal for differentiating varieties. If a choice between plants or the various progeny groups is to be made, rapid methods for comparing large numbers of progenies must be available. An X-ray diffraction method, developed by Berkley and Woodyard (*6*) and described in the first section (pp. 3 to 14) of this bulletin, may be used in selecting strains that will produce strong fiber. This technique was used by Ware and Harrell (*38*) in their study of inheritance of strength in upland cotton.

In applying this method in the spinning and fiber studies of new strains (pp. 15 to 31), it was observed that varietal characteristics influenced the application of the X-ray technique. Certain varieties of cotton and all varieties at certain locations gave stronger or weaker fiber and yarns than expected from the X-ray angles. Field damage is known to reduce fiber strength appreciably, whereas it has little effect on structure.[19]

This would account for the low strength values found at Baton Rouge in 1937. Obvious explanations, however, are not readily apparent for certain hereditary or varietal discrepancies, as in Farm Relief, Stoneville 5, and Wilds (Coker) 5; nor for certain environmental peculiarities, as for all varieties grown at Lubbock, Tex., in certain crop years.

It seemed desirable, therefore, to examine the relation of variety to fiber structure, as measured by the X-ray angles with respect to its possible utility to the cotton breeders for making improvement in fiber strength. Any method used as a basis of selecting cotton varieties is likely to be subject to certain limitations even within species. It is understood that correlations of fiber properties for environmental effects, i. e., within a variety, may give an entirely different result from those for hereditary or varietal effects. The response consequently becomes somewhat confusing if heritable and environmental effects are not clearly delimited and especially so if "variety" is not clearly defined.

In the varietal-strain studies it was found that the regression equations for predicting the Pressley indices from the X-ray angles were in general as follows: For sea-island cotton, $S=16.5286-0.2286X$; for

[19] Unpublished data obtained jointly by Harry Humfeld, Bureau of Industrial and Agricultural Chemistry, and Earl E. Berkley, of this Bureau.

American-Egyptian cottons, $S=15.8740-0.1800X$; and for American upland cotton, $S=12.3105-0.1497X$, where S=Pressley index and X=X-ray angles. For any given angle, the Pressley index was, therefore, about 2 pounds greater on the average for the sea-island and American-Egyptian cottons than for the upland strains. It also is shown that similar but smaller differences are found between the regression equations from varieties or strains within the same species. This study deals primarily with the relationships and differences existing within a species or among the American upland strains, with one example of a cross of two or more species.

The populations dealt with are admittedly small, and, while the trends shown here have been confirmed in other limited data from hybrid material, it is realized that more extensive genetic studies will be required to establish definitely the mode of inheritance for structure as revealed by the X-ray method.

Results

A commercial variety or strain of cotton may be referred to as a population of individuals similar in origin and characteristics. Varieties and strains may be distinguished from each other, since the differences within a population are less than the average of those between groups. Unless they have arisen as pure lines, however, they cannot be expected to breed true in the strictest sense nor to remain constant over a long period of years.

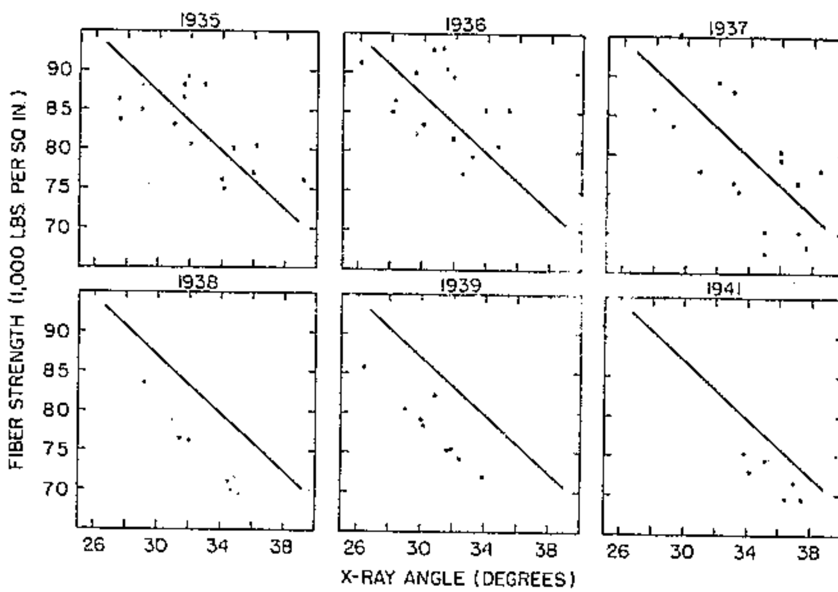


Figure 19. Fiber strength (Chandler bundle method) on the ordinate and X-ray angles on the abscissa for Wilds 5 (X) and Stoneville 5 (O) cottons. The dates indicate the crop years. The heavy line is the regression line for total in the covariance of the regional variety study for 16 varieties in 8 locations for 3 years.

Bearing in mind the restrictions imposed by the varietal characteristics, two of the well-known cottons of the regional variety test are compared. In general, the fiber strength of the Stoneville 5 cotton was lower than expected for the X-ray angles, whereas that of Wilds 5 was stronger on the basis of all varieties (fig. 19). For a given X-ray angle, the Wilds was about 9,000 pounds per square inch stronger than the Stoneville. Within each variety, there was a reasonably good negative correlation between strength and structure, except where field damage was pronounced. When the varietal averages were used, however, there was a positive relation between X-ray angles and fiber strengths. The Stoneville 5 cotton had an average X-ray angle of 31.1° and a fiber strength of 80.8 (1,000 pounds per square inch), whereas Wilds 5 had an average angle of 33.8° and a strength of 84.5.

CROSS OF TWO STRAINS

From the point of view of cotton improvement, the cotton breeder is interested in the genetic response of the progenies from a given cross. The extremes and the average X-ray angles from the parents and the F_1 to F_4 generations of a cross of two Acala strains are given in table 17. The parents and the F_1 represent the same crop year. It can be observed that the average X-ray angle of the F_1 was approximately the same as the average of the two parents. The X-ray angles from the F_2 and later generations may have been modified by seasonal or cultural conditions. They may have been influenced by selection also, although no conscious effort was made to select for large or small X-ray angles. Desirable plant and boll types were used, mainly as the basis of selection. Frequently, the parent with the best type of plant, as judged by the breeder, produces fiber with a relatively large X-ray angle.

The F_2 samples showed a smaller X-ray angle than the average of the two parents or the F_1 generation, whereas the F_3 and F_4 gave a somewhat larger average angle. The distribution of the X-ray angles in the F_2 and F_3 hybrids tends to spread to the extremes of the two parents. In the F_4, however, in which 9 of the 10 selections were derived from the same parent, the spread of the X-ray angles was only from 29.3° to 35.2°.

TABLE 17.—*The extreme and mean X-ray angles from the parents and from the F_1, F_2, F_3, and F_4 hybrids from a cross*

Strain or hybrid	Plants	Range in angles	Mean angle	Mean angles for parents
	Number	*Degrees*	*Degrees*	*Degrees*
Acala 22 (parent)	10	26.4 to 30.0	27.8	31.6
Acala Q 62 (parent)	10	33.8 to 36.3	35.5	
F_1 hybrid	10	28.6 to 32.1	31.0	
F_2 hybrid	34	27.5 to 34.6	30.5	
F_3 hybrid	13	30.2 to 37.3	34.3	
F_4 hybrid	10	29.3 to 35.2	32.3	

CROSS OF TWO VARIETIES

A cross of two varieties appears to follow the same course of inheritance as two strains in relation to fiber structure. In 1938 a cross was made with Durango, a variety with small X-ray angles and Acala Shafter, a variety with large X-ray angles. No attempt was made to study the progeny populations for fiber structural characteristics until 1943, and then only a fraction of the fiber material from the various progeny populations was available. A number of samples tested in the F_3, F_4, F_5, and F_6 generations, however, seemed worthy of study. The results, including X-ray angles and fiber strength, are shown in figure 20. In the F_1 and F_2 the data were not adequate for the study of spread in the X-ray angles, but in the F_4 the range was from 29.4° to 36.8°, with a mean of 33.2°, which was very close to the mean of the two parents. In the F_5 the range was from 29.2° to 35.0° and the mean was 32.9°, whereas the F_6 ranged from 28.7° to 38.8°, with a mean of 33.8°. The strength data based on the Pressley index and converted to pounds per square inch follow much the same distribution from the mean as the X-ray data (fig. 20).

In the course of breeding five distinct types were segregated from selections 9, 12, 19, 22, and 25 made in the F_2 generation. No. 9 was dropped after the fourth generation. The other four have been carried through six generations. When the X-ray data from these were studied, it was found that No. 25 showed consistent differences in fiber structure from the other three lines. In all samples representing individual plants or several plants combined, the X-ray angles were relatively small and fell within a narrow range not much higher than the Durango parent.

Another line originating from selection No. 12 showed more inherent characteristics of the Acala parent than the others. The X-ray angle tended to be large, but with a wide range, which allowed continued selection for desirable fiber structure.

In making plant selection in the F_2, F_3, and F_4, the plant and boll type, fiber length, and lint index were used as guides without resorting to X-ray or fiber-strength measurements. Fortunately, progeny line No. 25 was not eliminated, since it possessed desirable plant characteristics and high yielding capacity as well as superior fiber structure and strength. The value of the X-ray is indicated in detecting such qualities in the early stages of segregation. The behavior of the No. 25 line in proving fairly homozygous for small angle and high tensile strength suggests that the inheritance of fiber structural characteristics may not be so complex as its quantitative nature might indicate.

It is indicated further (fig. 21 and table 17) that a characteristic structure for a given strain where segregation is not pronounced is

TABLE 18.—*X-ray angles from 6 self-pollinated pedigreed sib lines of cotton, variety Nucala, grown at Greenville, Tex., 1940 cr*

Pedigree	X-ray angle	Pedigree	X-ray angle
	Degrees		*Degrees*
16-7-1-18-8-3-2-10	31.4	16-7-1-18-13-1-8-1	32.0
16-7-1-18-9-4-3-1, plant 10	31.2	16-7-1-18-23-5-5-4	32.2
16-7-1-18-9-4-3-1, plant 15	32.1	16-7-1-34-14-1-7-6	32.2

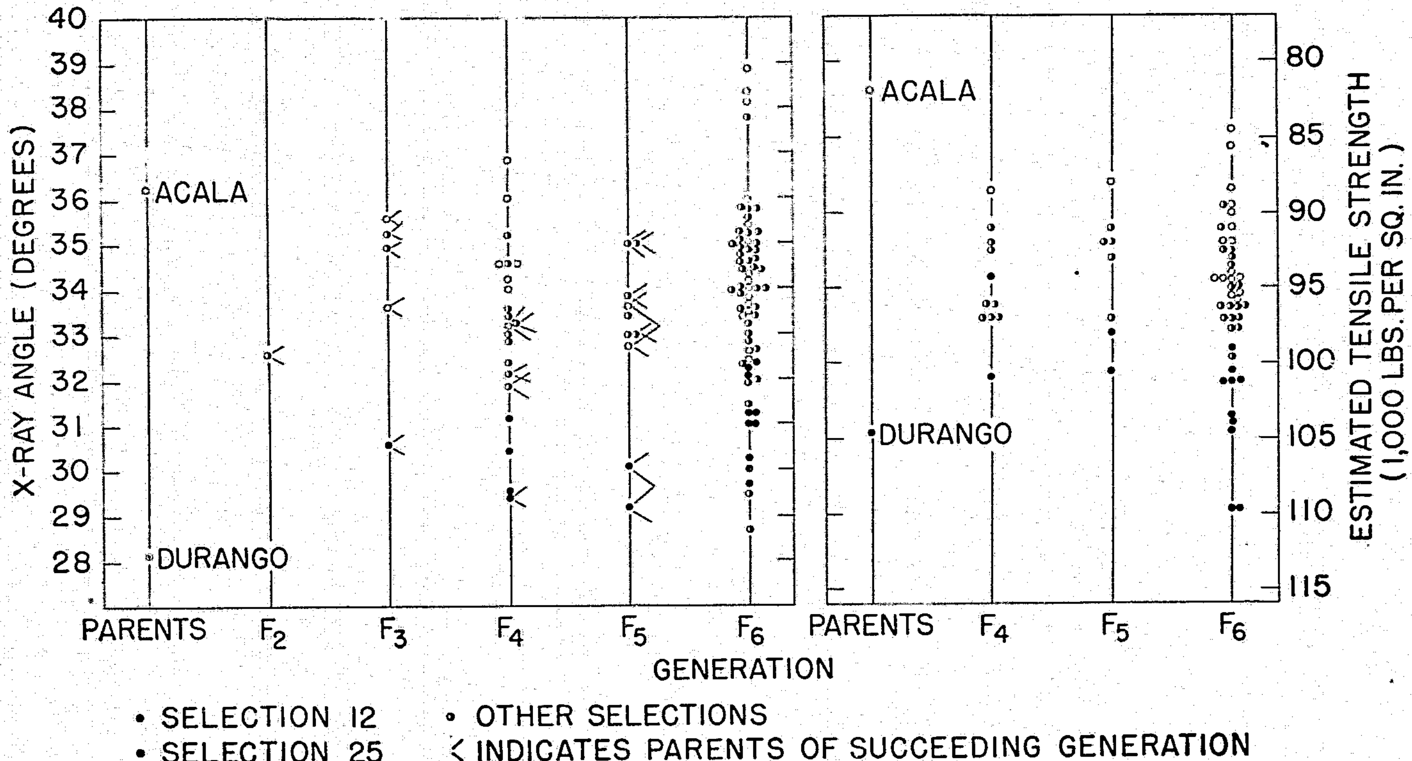


FIGURE 20.—Inheritance of X-ray angle and fiber strength in an Acala-Durango hybrid.

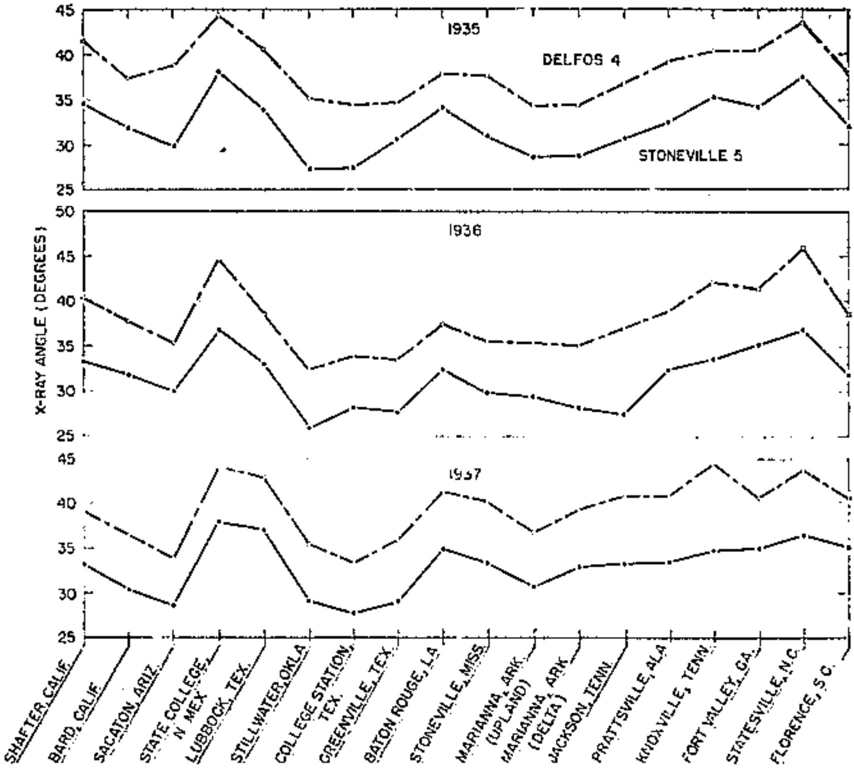


FIGURE 21.—X-ray angles from 2 varieties of cotton grown at 18 locations throughout the Cotton Belt for 3 consecutive years. Each variety kept its respective position at all stations and in all years.

more or less stable. Figure 21 gives data for two varieties, Stoneville 5 and Missdel 4, grown side by side for 3 consecutive years at 18 locations throughout the Cotton Belt. There was a reasonably constant difference in the structures of the two varieties irrespective of location or seasonal effects. Six similar selections from a single strain, some of which had been separated for five generations, are shown in table 18. The X-ray angles are within the limits of experimental error.

CROSS OF TWO OR MORE SPECIES

Because of differences in chromosome numbers, it is necessary to use special technique when crossing certain species of cotton. Beasley (*4*) succeeded in crossing widely different cottons by the use of colchicine and special culture technique. The results obtained when a triple hybrid was backcrossed to American upland cotton and produced fiber of unusual characteristics is diagrammed in figure 22. (See footnote 11, p. 18.) Unfortunately, no detailed study was made of the fiber from plants of the two parents grown with the progenies, but such information as is available indicates that the X-ray angles of *Gossypium arboreum* var. *nanking* would be about 35° and of the American upland about 38° when grown beside the triple hybrid, which gave an X-ray angle of 20°. The small angle was apparently inherited from the lintless cotton *G. thurberii*, a wild American species.

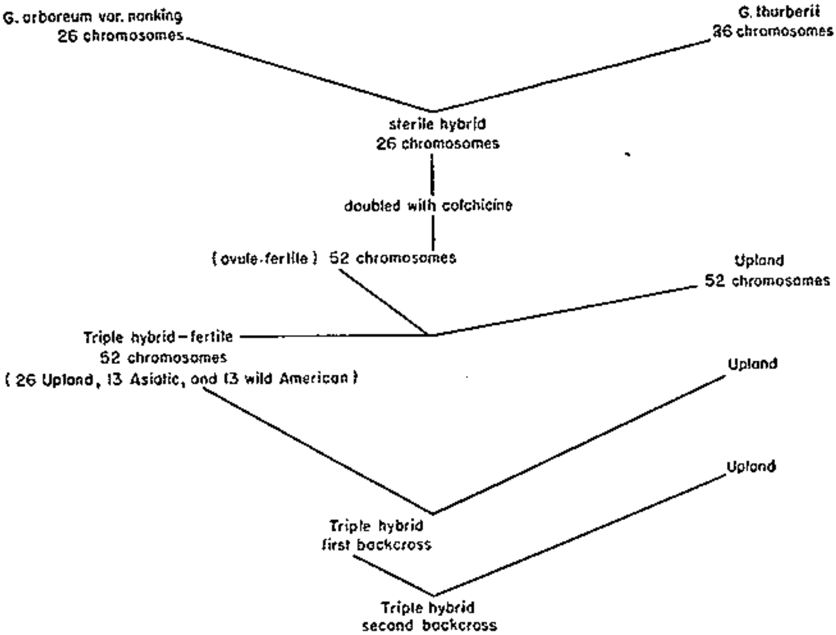


FIGURE 22.—Diagram of triple hybrid and backcross, showing parents and stage where chromosomes were doubled by use of colchicine. This cotton was bred by Dr. Thomas Kerr and the late Dr. J. O. Beasley, at the North Carolina State College, Raleigh.

Other hybrids resulting from crosses of widely different species have been successful in producing cottons with small X-ray angles and excellent fiber strength. If these characteristics can be combined with the high-yielding characteristics of the better American upland strains, superior cottons will result.

DISCUSSION AND CONCLUSIONS

It may be concluded from the data available that the structural-strength relationship is somewhat different in different species of cotton and occasionally in different varieties of the same species. The comparison of X-ray angles, therefore, as an index of the strength or commercial value of a sample should be limited to a given species or group, unless a conversion factor is used in going from one to the other. On the other hand, the structure of the fiber as shown by X-ray angles is sufficiently constant within a well-established strain for comparisons between strains to be made under a given environment. When two widely different strains are crossed, the structure of the F_1 hybrid may be equal to the average of the parents or better, with wide segregation in the second and succeeding generations.

The X-ray methods, as described on pages 57 to 61, can be used to advantage where selections for strength of fiber are desired. Since the X-ray angles are not materially affected by the usual field damage occurring while the cotton is open on the plant, the technique should be particularly valuable to cotton breeders. It is recognized that more data are necessary for final conclusions on the mode of inheritance of fiber structure and strength.

OUTLINE OF X-RAY METHOD

By Earl E. Berkley

Preparation of Sample

SUBSAMPLE

A laboratory sample is drawn by taking small pinches (50 to 100) at random throughout the bulk sample. Care should be exercised to be sure that the subsample is representative of the entire sample to be studied. The laboratory sample is divided or pulled a number of times between the hands and drawn into a hand sliver. The sliver is folded about three or four times and again divided between the hands several times.

BUNDLE

The blended sample should be broken between the hands and small tufts of fiber sufficient to make a bundle pulled from the break. Use care in excluding lumps or tufts of fibers that were not mixed in drawing the sliver. Comb each end of the rough bundle 15 strokes in the coarse comb (fig. 23) by grasping the bundle about one-eighth inch from center and combing the long end. Then comb each end of it 20 strokes on the fine comb and adjust to the appropriate size after

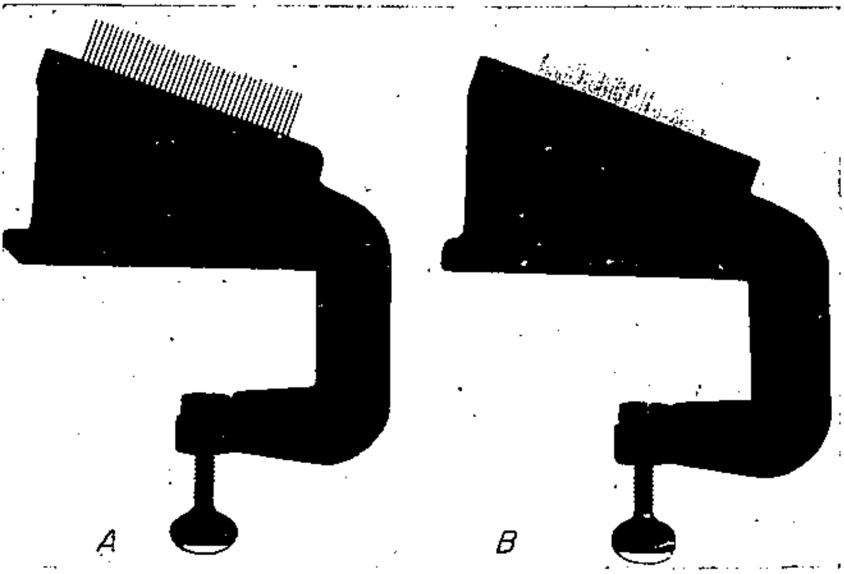
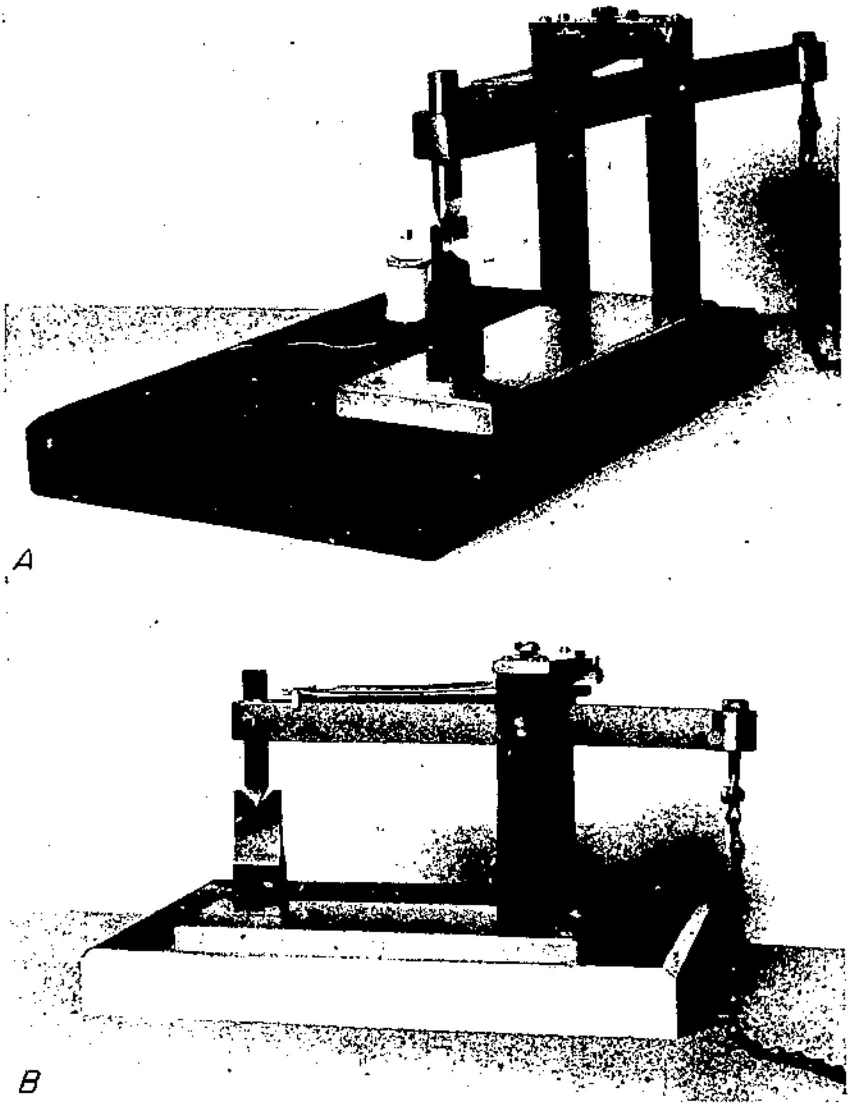


Figure 23.—Coarse comb (*A*) and fine comb (*B*) used in preparing X-ray bundles.



A

B

FIGURE 24.—Pressure device for tying cotton bundles for use in X-ray method of testing fiber structure and strength: *A*, Front view, bundle of cotton in slot with plunger holding it in place, spring adjusted to compress the cotton into a compact bundle; *B*, side view, showing detail of slot and plunger.

weighing. The recommended bundle size is approximately 0.125 inch in circumference, as measured by the wrapping procedure described for the Chandler bundle method (*24*). A somewhat smaller bundle may be used, but larger bundles are not recommended. After adjusting to size, comb each end again 15 strokes on the fine comb and reweigh. If further adjustment is necessary, comb only sufficiently to smooth out the bundle. Place bundle in clamp (fig. 24)[20] and tie each end close to the clamp, using a miller's knot or clove hitch. This should be done with care so as to avoid twisting or otherwise distorting the bundle.

Preparing the X-Ray Patterns

Place the bundle in the tension device (fig. 25), using care not to allow it to twist or otherwise become distorted or roughed up. Apply 10 pounds' tension for bundles of standard size, proportionally less for ½- or ¾-size bundles, and place in position on the X-ray unit at right angles to the direction of the X-ray beam. A collimator opening of 0.033 inch has been found satisfactory for routine tests.

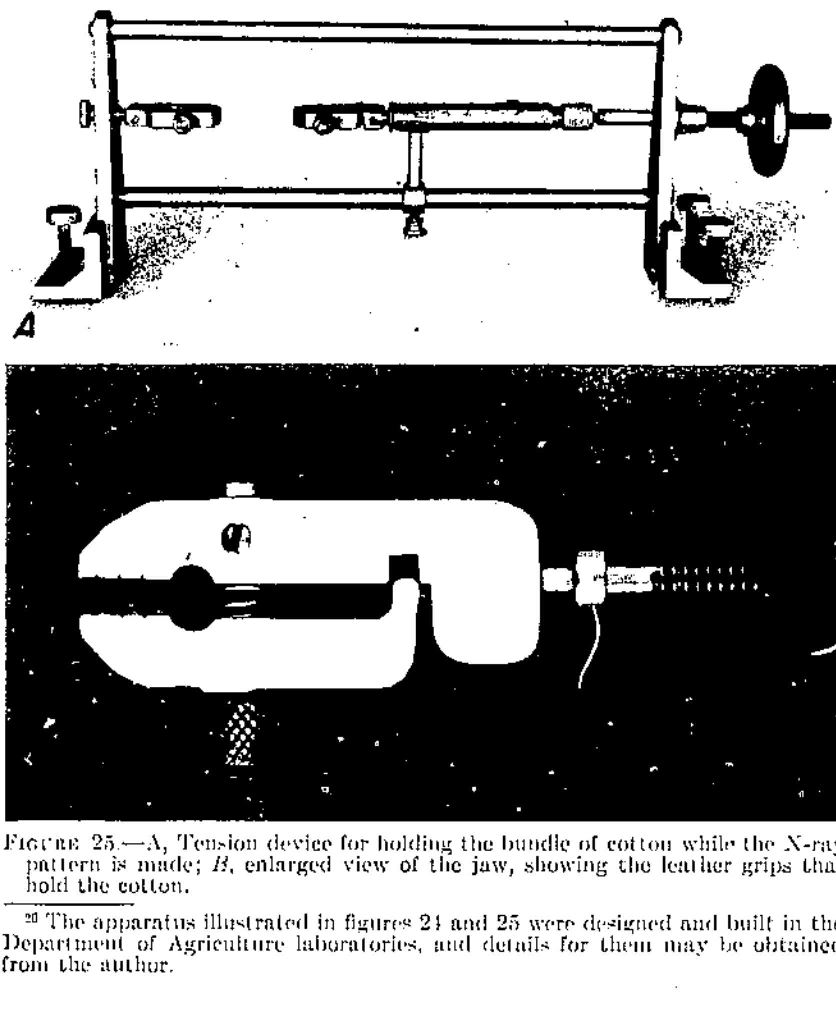


Figure 25.—A, Tension device for holding the bundle of cotton while the X-ray pattern is made; *B*, enlarged view of the jaw, showing the leather grips that hold the cotton.

[20] The apparatus illustrated in figures 24 and 25 were designed and built in the Department of Agriculture laboratories, and details for them may be obtained from the author.

Place the film in the holder, adjust the distance from sample to film, and expose so as to get a photographic density sufficient to give approximately 180 scale divisions on the microphotometer at the darkest point in the 002 arc. A distance of 4 cm. from specimen to film was used to obtain the data reported in this bulletin, but greater or smaller distances can be used with little change in results. The exposure time varies, however, with specimen-to-film distance.

Develop film according to manufacturer's recommendation, which usually calls for a 5-minute development period at 65° F., wash for 30 seconds, fix for 12 minutes, wash again for 30 minutes, and then rinse and dry. In rinsing, the film should be swabbed off thoroughly with a soft, cellulose sponge or absorbent cotton so as to remove any film or sediment deposited from the wash water. Set film racks on edge while drying to prevent the water on the clips from running over the X-ray pattern.

Measuring the X-Ray Angle

The microphotometer used for measuring the patterns has been fully described by Berkley and Woodyard (*6*), and the details on calibration will be found on pages 7 and 14.

Since that time, a few minor changes have been made that should be noted. The most important has been in the galvanometer. A new system, using a taut suspension, has been installed. This unit has a sensitivity of 0.012μa. per millimeter at 15 inches and a period of 3.5 seconds. This gives greater stability from mechanical shock and permits more rapid readings. The galvanometer scale has been curved so as to give correct readings at all points. In addition the film holder has been replaced by one of a different design that presents a larger surface in contact with the film and thus holds the film flatter; and a shield has been installed that protects the photocell from any external light that may enter through the translucent galvanometer scale.

First check the zero setting of the galvanometer and the intensity of the light by adjusting the voltage so that the galvanometer reading is 90, the usual setting on the standard filter. Place the pattern in the film holder of the microphotometer so that the ends of the arcs are equally spaced in regard to the cross hairs on the centering device, fasten the clamp, and center the pattern, using the photocell system, so that both arcs pass over the slit when the film is rotated by means of the rotary stage. Take the maximum microphotometer readings in the vicinity of the 0° and 180° positions and the minimum readings at or near the 90° and 270° positions. It may be necessary to rotate the film slightly to the left and right of these four positions to make sure that the largest possible readings are obtained in the region of 0° and 180° and the smallest possible for the 90° and 270° positions.

Subtract the minimum from the maximum reading in each quadrant, calculate 40 percent of the difference, and add to it the minimum reading. Rotate the stage until the microphotometer gives the calculated value in each quadrant and record the degrees of rotation of the stage from zero in each quadrant. When all readings on the pattern are finished, remove it from the stage and recheck the microphotometer for the zero setting and the reading from the standard filter.

Calculate the angular rotation from 0° in the first and fourth quadrants and from 180° in the second and third quadrants, determine the mean of the four angles, and correct it to a given relative transmission, using table 19, by adding the value indicated for each scale division below 180 (180 equals a relative transmission of 0.20) and subtracting for each scale division above 180. Unless all photometers in question are of the same design, the scale reading at a transmission of 0.20 may vary from one instrument to the other. Record the corrected angular reading. This is the X-ray angle for one bundle. The average of two to three bundles from a well-mixed sample should be ample. More are necessary, however, if the sample is not carefully blended. The experimental error differs from one lot of samples to another, but an error of ±1.0° is conservative on the basis of approximately 2,000 observations made by different operators and using a wide range of photographic intensities.

TABLE 19.—*Corrections for variations in film transmission to be applied to the X-ray angles* [1]

Photometer reading, arbitrary scale	Correction for angle	Photometer reading, arbitrary scale	Correction for angle	Photometer reading, arbitrary scale	Correction for angle
	Degrees		*Degree*		*Degrees*
140	+1.4	167	+0.6	194	−1.0
141	+1.4	168	+.6	195	−1.0
142	+1.4	169	+.5	196	−1.1
143	+1.4	170	+.4	197	−1.2
144	+1.3	171	+.4	198	−1.3
145	+1.3	172	+.3	199	−1.3
146	+1.3	173	+.3	200	−1.4
147	+1.3	174	+.3	201	−1.5
148	+1.3	175	+.2	202	−1.6
149	+1.2	176	+.2	203	−1.7
150	+1.2	177	+.1	204	−1.8
151	+1.2	178	+.1	205	−1.9
152	+1.2	179	+0	206	−2.0
153	+1.2	180	+0	207	−2.1
154	+1.1	181	−.1	208	−2.2
155	+1.1	182	−.1	209	−2.3
156	+1.1	183	−.2	210	−2.4
157	+1.0	184	−.3	211	−2.5
158	+1.0	185	−.4	212	−2.6
159	+1.0	186	−.4	213	−2.7
160	+.9	187	−.5	214	−2.8
161	+.9	188	−.6	215	−2.9
162	+.9	189	−.6	216	−3.0
163	+.8	190	−.7	217	−3.1
164	+.8	191	−.8	218	−3.2
165	+.7	192	−.8	219	−3.3
166	+.7	193	−.9	220	−3.4

[1] The corrections are based on the microphotometer readings at the position of maximum absorption on the arcs from the 002 planes. A photometer reading of 180 is equal to 0.20 relative transmission, and a range of approximately ±0.10 in minimum relative transmission can be tolerated when these corrections are used.

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