Chapter 24

# STRESS INFLUENCES ON FIBER DEVELOPMENT

Harmon H. Ramey, Jr.[1]
USDA—ARS
New Orleans, Louisiana

## INTRODUCTION

The cotton fiber develops from a single epidermal cell of the seed coat (Stewart, 1975). The cell elongates for approximately 20 days and then deposits secondary wall for a subsequent 20 or more days (Ramey, 1980; Walhood and Addicott, 1968). The two processes appear to overlap (Schubert *et al.*, 1973). This biological system has constraints; otherwise, a fiber cell would elongate infinitely and/or the secondary wall would develop such that the fiber cell becomes a solid cylinder. A given cultivar grown in a given environment will produce fibers of a given length and a characteristic amount of secondary wall deposition. Therefore, it can be inferred that fiber length and secondary wall deposition are under genetic control. The growth environment determines whether or not the fiber length and secondary wall deposition reach the potential of the genotype. Departures from optimum growth conditions, or stress, affect the ultimate dimensions. For purposes of this discussion the term "stress" is used for any departure from optimum growth and fruiting conditions.

## MORPHOLOGICAL PROPERTIES

Cotton evolved in the subtropics where the plants grow as perennials (Hutchison *et al.*, 1947). In less than 300 years, upland cottons (*Gossypium hirsutum* L.) and Egyptian and Pima types (*G. barbadense* L.) have been adapted to annual culture so that the major production areas are now in the temperate regions (Lewis and Richmond, 1968).

The annual growing cotton plant can be visualized as an inflorescence on a root system. The vegetative part of the plant is less than eight nodes of the main stem (Ewing, 1918). On the average, blooms appear at three-day intervals on the first node of successive fruiting branches up the stem and at six-day intervals at successive nodes on a given fruiting branch (Tugwell and Waddle, 1964). (For details of this process see Chapter 2). Because of the sequential development of

[1]Presently with USDA-AMS, Memphis, TN

the plant, at a given time fibers in some bolls will be elongating and fibers in other bolls will be depositing secondary wall. Thus, stress at a given time will affect the elongation of some fibers and the secondary wall deposition of other fibers on the same plant. For this reason, the effects of stress on cotton fiber growth and development are difficult to assess when all bolls on a plant are sampled for fiber measurements. When individual bolls are considered, stress during the elongation phase will cause shorter fibers and during the wall deposition phase will cause thinner secondary walls. The latter condition is frequently referred to as immaturity. Specific factors that influence fiber growth and development are treated separately in the following.

## MINERAL NUTRIENTS

The extension or elongation of the cotton fiber is dependent on turgor pressure within the cell. Potassium and malate, which accumulate in the fiber and reach peak levels when growth rate is maximum, can account for more than half the osmotic potential (Dhindsa *et al.*, 1975). In field fertilization experiments additions of some potassium fertilizer increased both fiber length and cell wall development (Bennett *et al.*, 1965, 1967; Nelson, 1949). Additional increments of potassium fertilizer had little effect on either. Potassium deficiency caused shorter and lesser developed fibers.

Nitrogen fertilization has been shown to increase fiber length (Jackson and Tilt, 1968; Wadleigh, 1944) although others have observed little or no effect from nitrogen (MacKenzie and van Schaik, 1963; Nelson, 1949). Additions of boron have been shown to increase secondary wall deposition (Anderson and Boswell, 1968). The effect of nitrogen or boron deficiency is probably on the development of the plant rather than on the fiber directly. This contrasts to potassium deficiency which alters the osmotic potential of the fiber cell itself and thereby reduces the length development. Good management practices that prevent mineral element deficiencies eliminate this source of stress. (See also Chapters 9, 10, 20 and 21).

## TEMPERATURE

Cotton growth and development are affected by temperature. Boll period, the time from open bloom (anthesis) to open boll, increases as temperature decreases (Gipson and Joham, 1968a; Yfoulis and Fasoulas, 1978). Night temperatures generally exert more effect than day temperatures (Gipson and Ray, 1969b). However, the effect is not unidirectional because day temperatures above about 32C can increase boll period (Yfoulis and Fasoulas, 1978). Johnson and Wadleigh (1939) reported increases in yields with increases in July average maximum temperature up to 35C and decreases in yields as the July average maximum temperature exceeded 35C. These findings support the concept that there is an optimum temperature for cotton growth and development and that growth will decrease at temperatures above and below this optimum. The optimum is not well defined but may be a characteristic of a cultivar.

Generally, the average temperature declines from the time of boll set until boll opening in most production areas of the northern temperate zone. Typical decreasing temperatures for Lubbock, Texas are shown by Bilbro and Ray (1973). Decreasing temperatures have a retarding effect on elongation and cell wall development (Hawkins and Serviss, 1930).

Night temperatures below 22C increase the time required for fibers to reach the genetic potential for length (Gipson and Joham, 1969a; Gipson and Ray, 1969a). The maximum length of fiber was obtained when night temperatures were between 15 and 21C and reduction in length occurred above and below this temperature range (Gipson and Joham, 1968b; See Chapter 5).

Decreasing night temperatures affect cell wall development more than fiber length (Gipson and Joham, 1968b). The low-temperature effects on cell wall development are more pronounced in the northern temperate zone because of the sequential development of the fiber. Bolls are set in the warmer part of the season and mature under decreasing temperatures, particularly bolls set later in the season. In an area where the bolls set during six weeks, the mass per fiber declined from the second to the sixth week of boll set (no data were reported for the first week of set) (Turner *et al.*, 1979). Planting time affects fiber development by influencing the period at which the majority of the bolls are set. Bilbro and Ray (1961) showed that the micronaire reading, an indication of cell wall development, was highest (more development) in fiber from April 20 plantings and was lower (less development) in fibers from plantings after June 1. Bolls set later in the season produced fibers with lower micronaire reading (Hessler *et al.*, 1957, 1959). The micronaire reading of fiber produced in the warmest of three environments was highest (Quisenberry and Kohel, 1975). These results should be expected because micronaire reading was reduced by reducing night temperature below 25C (Gipson and Joham, 1968b; Gipson and Ray, 1969b).

Conner *et al.* (1972) demonstrated that lower temperatures can affect plant processes involved in fiber formation. Soluble sugars were present in higher concentration in bolls less than 15 days postanthesis from plants grown with 25C night temperatures than in the same age bolls from plants grown at lower night temperatures. There were more soluble sugars present in 40-day old bolls grown at 10C and 15C than in those same age bolls grown at 20C and 25C. These data indicate that low night temperatures affect the production or accumulation of sugar and may affect the use of sugar in fiber development.

In the subtropics, blooms occur during the cooler part of the season (Mauney and Phillips, 1963). Fibers elongate in cooler temperatures and deposit the secondary wall in increasing temperatures. The temperature optima of 15 to 21C for fiber elongation and above 25C for fiber wall deposition favor fiber development in subtropical conditions. However, in temperate regions to which cotton has been adapted, the fibers elongate in the warmer part of the season and deposit secondary wall in decreasing temperatures. The physiological processes have not been sufficiently altered in the adaptation to an annual temperate culture to prevent stress on the developing fiber. The stress occurs because the temperature trends in the temperate region culture are opposite to the temperature optima for fiber development.

## MOISTURE

Inadequate or excess moisture can affect the growth of the cotton plant and, thereby, the fiber. Although excess moisture is usually not considered stress, Jackson and Tilt (1968) reported shorter fibers from plots in Arizona which were irrigated every 7 days than from plots irrigated at 14-day intervals. When the irrigation interval was extended to 21 or 28 days, the fibers were shorter than those from the 14-day irrigation interval. Drought or deficient moisture tends to reduce fiber length (Bennett *et al.*, 1967; Eaton and Ergle, 1952, 1954; Marani and Amirav, 1971; Shimshi and Marani, 1971; Sturkie 1934, 1947). Increased amounts of moisture tend to increase fiber length (Grimes *et al.*, 1969; Newman, 1967; Spooner *et al.*, 1958). However, in many cases alterations of moisture regime do not affect fiber length, as was mentioned in several of the above cited reports and by Bilbro (1962). Only when plants were severely stressed in the early blooming stage were substantial effects on fiber length noted (Jackson and Tilt, 1968; Marani and Amirav, 1971).

Some moisture deficit may not affect cell wall development (Sturkie, 1947). However, soil moisture deficit or excess throughout the season can reduce micronaire reading (Jackson and Tilt, 1968). Drought may or may not affect micronaire reading, but a severe drought or moisture deficit will reduce micronaire reading (Eaton and Ergle, 1952; Marani and Amirav, 1971; Shimshi and Marani, 1971). Lower micronaire readings were obtained from increased soil moisture (Eaton and Ergle, 1954; Grimes *et al.*, 1969; Shimshi and Marani, 1971; Spooner *et al.*, 1958). Adequate soil moisture increases micronaire reading (Bennett *et al.*, 1967; Marani and Amirav, 1971; Spooner *et al.*, 1958).

The effects of moisture stress on fiber development are difficult to ascertain. Moisture deficit reduces yields by reducing plant development (height) and the number of bolls per plant. The plant tends to compensate for lack of moisture by shedding fruiting forms and, thereby, to some extent alleviating stress on the remaining fruiting forms. The effects of short periods of moisture deficit or excess may not be reflected in a sample from the total production. However, a deviation from optimum moisture will cause shorter fibers with less-developed cell walls in bolls which are in the stage to be affected. The optimum moisture has not been defined. (See Chapter 7 for additional discussion on water deficit.)

## LIGHT INTENSITY

Leffler (1976) reported that bolls did not gain mass during a period of overcast sky. The period of low light intensity occurred during secondary wall deposition. It is not known whether the cessation of mass accumulation resulted in less secondary wall deposition nor whether the secondary wall deposition continued to the usual limit after the period of overcast sky. Also, it is not known what effect the period of overcast sky would have had on fiber length if it had occurred during the elongation of the fiber cell. The overcast sky must have reduced photosynthesis and, thereby, materials for boll synthesis. Shade has been shown to increase fiber length and reduce micronaire (Eaton and Ergle, 1954). The shade effect may have been indirect by reducing temperature slightly since the effects on fiber were similar to those that result from cooler temperatures.

## PESTS AND PESTICIDES

Most insects and diseases cause shedding or destruction of the fruiting forms or bolls that result in yield losses rather than altered fiber properties. Two diseases, however, cause changes in fiber development similar to severe moisture deficit. *Phymatotrichum* root rot reduces secondary wall development but does not alter fiber length (Eaton *et al.*, 1946). *Verticillium* wilt reduces both fiber length and micronaire (Bugbee and Sappenfield, 1970; Cotton, 1965).

Generally, insecticide applications do not affect fiber properties (Finley *et al.*, 1964), but some effects have been noted. Application of Guthion at low rates, Guthion plus DDT and Dieldrin plus DDT increased micronaire (Hacskaylo and Scales, 1959). Guthion plus DDT application also reduced fiber length. How these insecticides act to cause the altered fiber properties is unknown but the effects are similar to those from increased temperature.

Santelmann *et al.*, (1966) found that applications of herbicides did not affect fiber properties.

## GROWTH REGULATORS

Application of the growth inhibitor, maleic hydrazide, tends to reduce wall development (Ergle and McIlrath, 1952). Defoliants are growth regulators which cause abscission of leaves. Premature application of defoliants will reduce micronaire reading (Tharp *et al.*, 1961) and can reduce fiber length (Brown and Hyer, 1956). If the bolls are beyond 80 percent of the boll period when the defoliant is applied, only a minimal effect on micronaire reading can be detected (Walhood and Addicott, 1968). (See chapters 13 and 14 for information on growth regulators.)

## GENOTYPE INTERACTION

Differential responses of cultivars to temperature have been noted. Gipson and Joham (1968b) found Paymaster 54B more tolerant to lower night temperature than Acala 1517BR-1. The average daily gain in fiber mass per boll at 8C was greater in Paymaster 54B than in Acala 1517BR-1, but at 25C it was greater in Acala 1517BR-1. Elongation rates of fibers of three cultivars were influenced more by lower night temperatures than were those of two other cultivars (Gipson and Ray, 1969a). Quisenberry and Kohel (1975) demonstrated differences among cultivars in fiber development at lower temperatures. These examples illustrate that some genotypes tolerate a specific stress better than do others.

Plant morphology can affect the ability of a cultivar to withstand stress. Hawkins and Peacock (1968) reported that two cultivars produced longer fiber when grown in a solid planting pattern; whereas, most cultivars produced longer fibers when grown in a skip-row configuration. There should be less stress for the plants in a skip-row planting pattern because the plants would have more space. The two exceptional cultivars both produce larger bolls and fewer bolls are required to achieve a given yield level. The fewer bolls could be set in a shorter time period (Tugwell and Waddle, 1964), and the fibers could reach ultimate length before stresses affect fiber elongation. These same cultivars grown in skip-row planting pattern produced more bolls, and the yields were higher. If the temperatures were higher later in the blooming period, the fibers may have been shorter due to the effect of higher temperatures (Gipson and Joham, 1968b). The cultivars that produce smaller bolls would require more time for boll set and lack of moisture due to the spacing could have caused the shorter fibers in the solid planting pattern as compared to the skip-row planting pattern. The morphology of the plant can affect the ability of a genotype to escape stress.

There is a genotype effect in the response to stress. Some genotypes have the inherent ability to tolerate a specific stress more than other genotypes. Some genotypes can escape a specific stress because of certain morphological features. Specific stresses can be alleviated more readily with certain genotypes than with others.

## MECHANICAL PROPERTIES

The mechanical properties (strength and elongation) of the cotton fiber are affected by the amount of secondary wall deposition. Waterkeyn *et al.* (1975) have shown the angle of cellulose fibrils to the major axis of the fiber decreases from the primary wall inward. Evaluation of cotton fibers in flat bundle tests involves the application of a force in the direction of the major axis. The composite angle of the fibrils to the major axis influences the amount of strain (elongation) the fiber will undergo before rupture. The applied force tends to straighten the fibrils toward the major axis. Fibers whose secondary wall deposition has been arrested by some factor will exhibit greater elongation-to-break than fibers whose secondary wall deposition has proceeded to the normal limit. The composite angle of the fibrils in the less developed secondary wall will be greater, and the change in angle due to applied force will likewise be greater. It should be noted that elongation-to-break is not necessarily recoverable elasticity. Data of Nelson *et al.* (1980), Ramey *et al.* (1982) and Rousselle *et al.* (1980) illustrate the reduced elongation-to-break of fibers that have greater secondary wall development.

Most fiber strength data are from flat bundle tests and are reported in a breaking force-to-mass ratio, either as tenacity or Pressley Index converted to pounds per square inch. The effect of secondary wall thickness on tenacity are illustrated in Figure 1. The maturity levels, 1 through 4 are 1.27, 1.94, 2.48 and 2.59 μm secondary wall thicknesses, respectively (Ramey *et al.*, 1982). When the jaws of the breaking clamps are closely appressed, zero gauge or $T_0$, the lowest tenacity is for the fibers with the least secondary wall development. In contrast,

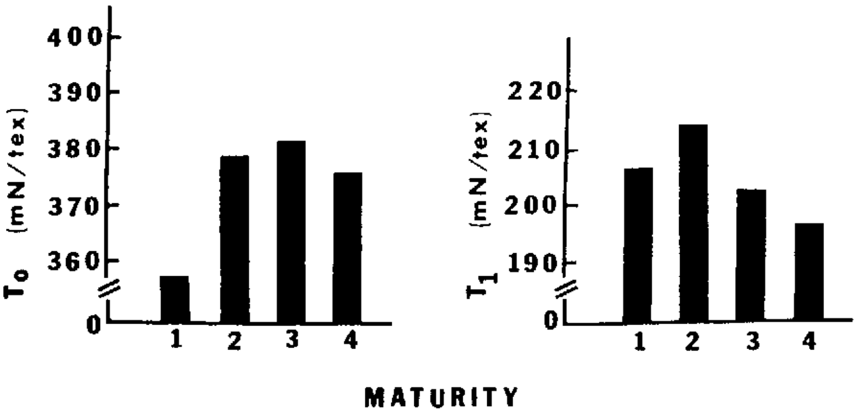


Figure 1. The tenacity of cotton fibers of four maturities. $T_0$ is the tenacity in flat bundle tests where the clamping jaws are closely appressed, zero gauge. $T_1$ is the tenacity in flat bundle tests where the clamping jaws are spaced 3.2 mm apart. The maturities 1, 2, 3 and 4 are 1.27, 1.94, 2.48 and 2.59 μm wall thicknesses, respectively. (Data from Ramey *et al.*, 1982.).

when the jaws of the breaking clamps are spaced 3.2mm apart, 3.2 gauge or $T_1$, the lowest tenacity is from the fibers with the greatest secondary wall development. Several reports indicate that fiber tenacity at 3.2 gauge is higher for lower micronaire reading samples (Bilbro and Ray, 1973; Jackson and Tilt, 1968). Hessler *et al.* (1957, 1959) reported increased zero gauge tenacity for higher micronaire reading samples. These results strongly suggest that fiber strength is affected only indirectly by stress. Factors that affect secondary wall development affect fiber strength.

When flat bundle test data are converted to force-to-break of individual fibers, the breaking force increases in direct proportion to secondary wall thickness. There was more than two-fold increase in breaking force as the secondary wall increased from 1.27 to 2.59 μm for both zero and 3.2 gauge (Ramey *et al.*, 1982). A fiber which has developed under stress conditions and, thus, has less secondary wall development is less resistant to breakage in processing. Short fibers generated by breakage during processing cause problems in the processing and reduce product quality.

## DISCUSSION

Stress, defined as deviation from optimum conditions, affects the growth and development of the cotton fiber. The effects of stress on the fiber are, for the most part, indirect. Stress affects the plant, and through the effect on the plant, affects the fiber. The fiber is an appendage of the reproductive unit, the seed. The developing reproductive unit is a stronger sink for the plant's resources than are the developing vegetative units. Thus, the fiber is usually less affected by stresses than are the other parts of the plant. For example, Grimes and Yamada (1982) have shown that under conditions of limiting moisture the growth and development of fiber (elongation and secondary wall development) continued at lower moisture availability than did main stem elongation. Many of the conflicting reports of the effects of stress on fiber morphology are due to the stresses acting on the plant and indirectly on the fiber. On the other hand, conditions that are optimum for growth of the plant are also optimum for growth of the fiber. Jackson and Tilt (1968) reported the longest fibers from treatments that produced the highest yields. This concept can be used to design cultural systems to produce optimum quality fiber as well as optimum yields for the genotype (Ramey, 1970). The sequential development of the fiber (Walhood and Addicott, 1968) and of the plant (Tugwell and Waddle, 1964) must be used in the design of systems. The blooming period is about six weeks (Turner *et al.*, 1979). Boll-development periods increase as the temperature increases above 32C (Yfoulis and Fasoulas, 1978) or decreases below 25C (Gipson and Joham, 1968a; Gipson and Ray, 1969b). The time when stresses must be minimized to produce optimum quality fiber range from 13 to 17 weeks. The cultural system must be fitted to the favorable parts of the growing season (Ramey, 1970). Stresses can adversely affect fiber quality, but the use of a system to alleviate stresses during critical times can enhance the production of quality fiber.

The work of Yfoulis and Fasoulas (1978) strongly suggests that genotypes have an optimum temperature range of about 15.5C. Two groups of genotypes were identified; one which develops well between 16.5 and 32.0 C, and another which develops well between 15.0 and 30.5C. Gipson and Ray (1969b) and Quisenberry and Kohel (1975) identified genotypes that are more tolerant of cooler conditions. These observations suggest that genotypes can be developed for specific temperature ranges.

In developing cultural systems to alleviate stress at critical times, the capabilities of the genotypes must be considered. The cultural system may have to be adapted for each cultivar.

## SUMMARY

The cotton fiber develops sequentially to a character stic length and secondary wall thickness for the genotype. Deviations from optimum conditions or stresses

influence how near the fiber develops to the characteristic length and wall thickness. Fruiting forms appear on the plant at three-day intervals on the first nodes of successive fruiting branches up the plant and at six-day intervals at successive nodes out a fruiting branch. At a given time there are bolls on a plant in which the fibers are elongating and other bolls in which the fibers are depositing secondary wall. The timing of the stress of deviation from optimum conditions determines whether length or wall thickness is affected.

Potassium and malate are the major contributors to the osmotic potential of the developing fiber cell. Potassium deficiency limits fiber length. Other mineral nutrients affect fiber properties through action on the plant.

Fiber properties are probably more affected by temperature than any other environmental factor. The optimum range for fiber length development is 15C to 21C and shorter fibers are produced in temperatures above or below this range. The optimum temperature for cell wall deposition is above 25C. Bolls set late in the season in the north temperate zone produce fibers which deposit less secondary wall. The temperature optima are characteristic of short-day plants from the subtropics and have not been altered in the adaptation to an annual culture in temperate regions.

Deficit or excess moisture can shorten fibers and lessen secondary wall deposition. The plant tends to compensate for moisture stress by retaining fewer bolls so the effects of moisture stress on fibers are frequently small.

Low light intensity caused by an overcast sky can slow down or stop fiber development. The effect of shade is similar to a slight reduction in temperature.

Two diseases, *Phymatotrichum* root rot and *Verticillium* wilt, alter fiber properties similar to severe moisture deficit. Other pests have little effect because injured bolls are shed. Some insecticides can alter fiber properties but the action is unknown.

Premature defoliation can cause shorter fibers and, more frequently, less wall deposition.

Genotypes differ in response to temperature. Specific morphological traits can enable certain genotypes to escape stresses.

Mechanical properties of fibers are affected by the amount of secondary wall deposition. Fibers with less secondary wall deposition will exhibit greater elongation-to-break. In flat bundle tests, immature fibers may exhibit greater strength than mature fibers when clamping jaws are spaced 3.2 mm apart but less strength when clamping jaws are closely appressed. Force-to-break of individual fibers increases directly with increases in wall thickness.

Conditions which produce the longest fibers usually produce the highest yields. Cultural systems designed to alleviate stresses can produce optimum quality fiber and optimum yield. Cultural systems may have to be adapted for each cultivar.