ANALYSIS OF THE VARIABILITY OF FIBER QUALITY

P. Clouvel, J.L. Chanselme, M. Cretenet, E. Jallas
CIRAD-CA URSC,
Montpellier, FRANCE
R. Sequeira
USDA-ARS-CSRU,
Mississippi State, MS

Abstract

Research conducted at the CIRAD experiment station, Montpellier, France during 1995 and 1996 aimed to characterize the variability of fiber quality properties in terms of the driving factors: water and nitrogen supply. The choice of the fruit capsule (the boll) as the unity of production permitted to analyze the variability between experimental treatments as well as between individual plants in a given field. A model of decomposition of the lint index is proposed to link production (mass) to fiber quality characteristics such as the fiber length and lineic fineness. The approach is exemplified in this document by presenting the relations which were found between the number of fibers per seed and fiber length, two yield components which develop in succession. Based on the 1995 results, it appears that an important proportion of the variability in observed length is explained by competition phenomena between fibers within a seed and within a boll. The present results need to be validated but they may offer a theoretical mechanism to explain the factors which determine fiber length.

Introduction

Cotton producer income depends on the quantity of seed cotton produced and its quality. Income can be expressed as:

$$\boxed{\text{Income = Lint Mass x Lint Price + Seed Amount x Seed Price}}$$

Further, fiber quality affects lint price and seed price. The main quality characteristics driving lint prices are: length, maturity, grade and extraneous particles. Of these 4 characteristics, length and maturity are strongly physiologically and genetically dependent. Lint mass may be expressed as a function of the number of fibers, the fiber length and the fiber linear mass :

$$\boxed{\text{Lint mass = no.fibers* fiber mean\_length * fiber\_fineness}}$$

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 2:1415-1417 (1997)
National Cotton Council, Memphis TN

These characteristics can be categorized according to the chronology of fiber development within the capsule (or more commonly, the boll) (Mauney and Stewart, 1986).

1. Length from 0 to 30 days after anthesis (daa)
2. Fiber fineness corresponding to the fiber secondary cell wall development (maturity) from 15 days after anthesis (daa) to boll opening at 50 daa.

For each boll, the quality elaboration occurs at the same time than competitive phenomena at the whole plant scale, such as vegetative growth and overall boll development. Quality elaboration occurs also in competition between seeds inside a boll and between lint and the developing embryo and cotyledons within the seed (Sassenrath, pers. comm, 1997). Existing literature indicates that the position of the boll on the plant (Danforth et al., 1990, Muhidong, 1995, Sequeira et al. 1989) and environmental conditions are responsible for the observed variability in the fiber quality. This difference is observed among bolls within the same plant and between different plants within the same field. Behind the hypothesis of fiber quality homogeneity by position (such as advanced in Sequeira et al. 1992, and Danforth et al. 1990) there is the notion of plant stand homogeneity. Thus, observations within a given field show a great variability in fruit-bearing plants. From the source side, the following are examples of variable factors: a plant's leaf surface, the leaf surface of a fruit's sub-tending leaf, the length and diameter of internodes, the penetration of light, the period (duration) of sub-tending leaves. Similarly, from the sink side, the following are variable: the number of bolls per plant, the number of seeds per boll. All these factors affect the conditions of fiber elongation and development for the production of final fiber quality.

Recently, precise fiber analysis equipment (AFIS) permits the treatment of small volume samples, such as the fiber from a single boll. The particular AFIS instrument at CIRAD is capable of providing measurements of both fiber length and several indicators of cell wall development such as maturity and 'micronaire' (micron-AFIS). The 'by-boll' characterization permits to relate measures relative to the mass of a sample to fiber quality characteristics using the following decomposition approach:

$$\boxed{\text{Lint index = K*(no.fibers /seed * fiber mean\_length * Area)}}$$

where:
Lint index=mass of the lint of 100 seeds (g)
K=constant to standardize AFIS measurements to cellulose density no.fibers/Seed=number of fibers per seed
mean_length: mean length of fiber as measured by AFIS, based on the number of fibers analyzed.
Area=AFIS measurement of secondary wall thickening

The importance of the above decomposition is two-fold. It permits an understanding of the elaboration of fiber quality in order to link this knowledge to the much better studied aspect of yield elaboration. This approach also allows the indirect characterization of the number of fibers per seed (all the other components of equation 1 are measured). The number of fibers per seed develops before anthesis during a very short period. Thus, the number of fibers per seed component permits to complete the chronology of the elaboration of fiber quality by translating the physiological status of the boll at the moment of anthesis.

The experimentation established in Montpellier during 1995 and 1996 aimed to understand the origin of fiber quality variability in relation to water, nitrogen supply, and plant stand. The variability was measured at the level of the individual boll and studied at the scale of individual plants and of the entire experimental field. The results which will be discussed regard only the determinants of fiber length as a function of water supply considering the data from 1995.

Materials and Methods

Experiments were conducted at the Château de LaValette in the South of France in Montpellier at the CIRAD-CA experiment station. Soils were lime-sands. The general experimental design included three irrigation levels, three nitrogen levels, and three plant densities. The treatments were unreplicated, such that a total of eleven plots each with 12 rows, 12 m long with inter-row spacing of 0.8 m were established. The plant density common to all water treatments presented in this study was 5.6 plants/m^2, obtained by manual thinning on June 20. Planting was with a planter on May 6 for the 1995 experiments. The initial plant density was 8.25 plant/ m^2. Nitrogen was supplied as side-dressed urea as follows: 30 Kg N on April 5 and 60 Kg N on July 25.

Water was supplied during dry periods as needed and in addition to normal rainfall. The treatments were: ‘constant irrigation’ from planting to cut-out (Constant. I.), from planting to blooming (I. Till blo.) or from blooming to cut-out (I.from blo.). Irrigation was done using a sprinkler system using an arrangement of sprinklers in 9 X 9 m squares. Irrigation was initiated as indicated by the soil water potential measured using electric conductance meters (Watermark^{TM}). On July 25, I. from blo had received 95 mm of rainfall and emergence irrigation, 230 mm for the other treatments. From July 25 to October 15, I. from blo. and constant I. received 60 mm of irrigation and all treatments received 110 mm of rainfall.

Observations for each of the field plots were conducted weekly. These observations concerned agronomic aspects of growth (above-ground biomass and leaf surface) and also measurements of Nitrogen uptake dynamics by using destructive sampling of ten plants on each of four different dates (during four different phenological stages). For each plot, 20 individual plants were monitored using weekly plant mapping including observations of boll production, changes in boll diameter, leaf surface estimated through measurements of the (main) leftmost vein of the blade. AFIS fiber quality measurements were conducted for all bolls produced by the plants which were monitored each week.

For the fiber quality analysis, the Advance Fiber Information System (AFIS) from Zellweger Uster, SA, modules L, D, F, and M was used. The different modules corresponded to Length, Diameter, Fineness, and Maturity. The sample was prepared by homogenizing each sample by hand prior to introduction into the machine. The analysis is done on an individual fiber basis which permits to obtain distributions of length measurements by number and by weight, of diameter, of maturity (degree of secondary wall thickening, or theta parameter), and of fineness (linear density) (surface of the transverse section or area). From these distributions, different parameters are calculated by the AFIS system to characterize the fiber quality (mean, quantiles, fractions).

The precision of the AFIS measurements depends both on the number of samples analyzed by boll and the number of fibers per sample. The methodological work conducted at CIRAD-CA regarding the behavior of the AFIS instrument for the different fiber measurements, permitted the establishment of appropriate reference curves for the boll measurements. Figures 1 is an examples of applied to fineness (Area). A sample size of three replications of 1000 fibers each permits a good compromise between time required and precision obtained. The characterizations of each fiber quality property have the following precision:

Length by number:	= ±0.64 mm
theta:	= ±0.008 (unitless)
Area:	= ±1.93 m

Results and discussion

The experimental conditions were not intended to suggest new or optimal management strategies for production but rather were intended to generate conditions which would allow us to investigate questions regarding boll and fiber development under contrasted conditions.

Under conditions of non-limiting nitrogen supply and without plant growth regulators, the water supply is a determinant factor for growth (Mauney 1992). Figure 2 shows the evolution of the mean plant height depending on the irrigation treatment. The water stress provoked a fast decrease in the growth of plants in the ‘I .until Bloom’ treatment. Physiologically, the strong vegetative development of the Constant I. and I.from Bloom treatments suggests the existence of competition between growth and development during the fruiting period. Further, this effect is presumed to be followed by problems of light penetration for the filling of the bolls in the lower positions. First bloom overall appeared on July 25. In contrast, the blooming period (duration) was strongly influenced by water supply. The cutout dates were respectively 850, 980, and 1000 degree-days (ºD) for the treatments I. Permanent, I. until Bloom, and I.from Bloom.

The underlying notion regarding the decomposition of the lint index into three components elaborated sequentially over time was to link each component to the current physiological status of the plant (nitrogen and water status, vegetative development). This approach allows us to explain the sources of variability. This chronological interpretation raises the issue of the independence among the components of the lint index. On figure 3, fiber length is presented as a function of the number of fibers per seed. The number of fibers per seed represented on the figure is proportional to the real value following the relationship:

"number of fibers" =1000*Lint_index/(Afis_Length*Area). This "number" is proportional to the real number of fibers per seed with a ratio corresponding to cellulose density.

In figure 3, we observe that below 2.1 "fibers/seed" the distribution of lengths appears to be independent of the number of fibers per seed. In contrast, for values of "number of fibers per seed" above 2.1, we note the existence of a limitation on fiber length as the number of fibers per seed increases. This is particularly strong for the Const.I. treatment. Note that the actual value at which the length begins to be affected is modified by the specific water treatment. For example, for the Constant I. treatment, the reduction in length appears to be strong after a value of "number of fibers per seed" of 2.1, whereas for the I.until Bloom. treatment, the variability in length appears to be less showing a decrease after a "threshold" value of 2.4 for the AFIS length index.

In figure 4, the identification of the actual positions of the bolls on the plant is shown for I.until Bloom. treatment. For example, a value of 6.1 represents a boll position on the sixth main stem node and on the first node of this fruiting branch. There are two kinds of lines shown in the figure. These lines link high and low first positions for fruiting branches of a given plant. Dashed lines indicate areas where the traditional trends hold true, i.e., the decrease in length due to increasingly 'outward' locations of the boll. Solid lines indicate areas where this traditional approach is not true. Below 2.4 the hierarchization of lengths appears linked to position of the boll on the plant. In contrast, above the 2.4 threshold the "number of fibers per seed" becomes the limiting factor, independent of the boll position.

Conclusions

If the observations regarding fiber quality trends are confirmed by the results from the 1996 experiments, the existence of these threshold values for the number of fibers per seed suggests a classical phenomena of competition such as in the case of cereals between number of grains per square meter and the weight of individual seeds. If this is confirmed to be the case, it would mean that this represents a phenomenon of competition between fiber for length at the scale of the individual boll.

This observation opens an area of research for the number of fibers/seed and the "engines" of cellular elongation between the stages of the establishment of the initial cell wall (elongation, which requires very little assimilate) and what happens during the overlap which occurs when both elongation and fiber thickening occur concurrently.

References

Danforth, D.M., M.J. Cochran, J. Bernhardt, and J. Haney. 1990. An economic analysis of lint weight and fiber properties by fruiting position. Proc. Beltwide Cotton Conf. National Cotton Council. Memphis, TN. pp.412-421.

Mauney, J.R. and J.M. Stewart. 1986. Cotton Physiology. The Cotton Foundation, Publisher. 786 pp.

Muhidong, J. 1995. A cotton fiber quality model. Ph.D. Dissertation. Mississippi State University, Mississippi State, MS. p.138

Sequeira, R.A., N. D. Stone, M. Cochran, and K. M. El-Zik. 1989. Inclusion of plant structure and quality in a distributed delay cotton model. Proc. Beltwide Cotton Conference - Engineering Section. Nashville, TN pp 156-158.

Sequeira, R.A., M. Cochran, K. M. El-Zik, N. D. Stone and M.E. Makela. 1994. Inclusion of plant structure and fiber quality into a distributed delay cotton model to improve management and optimize proit. Ecological Modelling, 71(1994) 161-186.

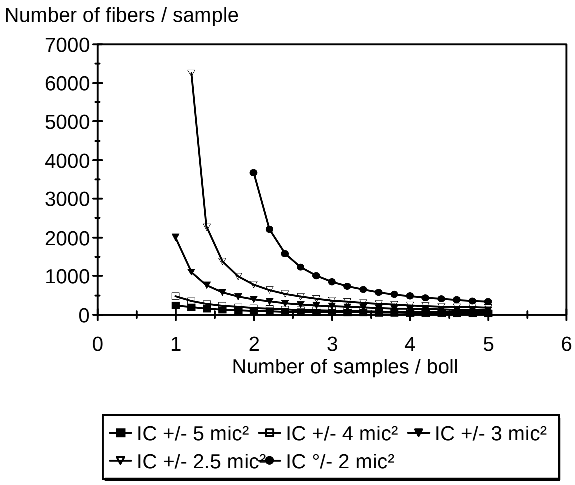

Fig 1 : AFIS Area Precision for Boll Analysis (30 bolls)

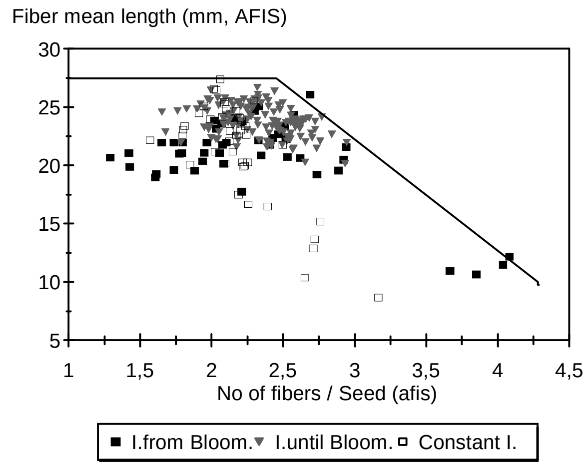

Fig 3: Fiber Length and Water Supply (DES 119)

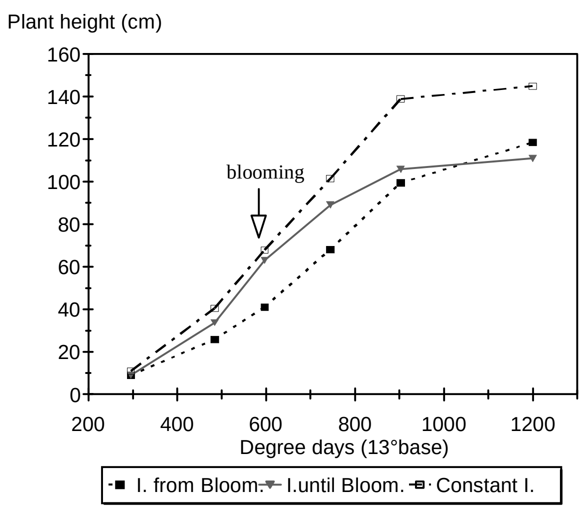

Fig 2 : Evolution of Plant Height

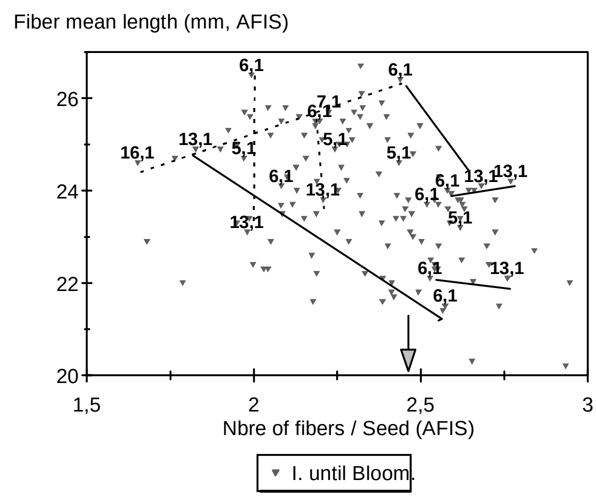

Fig 4 : Fiber Length Determinants Position and Competition (DES 119)