Variability of Cotton Fiber Quality

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ABSTRACT

Fiber quality variability is one of the key determinants of the profitability of the cotton crop. As variability increases, the risk associated with production increases and the expected return decreases. Prior to this study, variability had been characterized at the field or crop level. New technologies permit the analysis of very small samples, facilitating multi-scales studies. The variability in fiber properties is characterized and associated with genetic, environmental and production-linked sources. This research uses statistical models exclusively with the objective of studying the link between fiber quality variability and different levels at which it can be assessed in a cotton population. The treatments imposed on the different plots (water stress, nutrient levels, plasticulture) had as objective the induction of different variances in fiber properties, allowing the statistical associations to be made between sources and nature of the variability. It was possible to measure the effect of treatments on the number of bolls/m² and the vegetative development of the plants. Subsequently, changes in this variability at different scales in a production plot will be specifically associated and characterized.

Introduction

The variability of the fiber properties in cotton is an unfavourable element in a market that pits this natural fiber against artificial, more uniform products represented by synthetic fibers. The fact that a key source of the variability in the length and maturity of the fibers exists at the level of the point of fiber insertion on the individual seeds has been well documented (Iyengar, 1939). Fiber properties vary as a function of the cultivar but also as a function of the environment and production practices. Many researchers have shown the effect of water and nutrient stress, of plant growth regulators and more generally, of factors that affect the supply-demand relationships within the plant, including effects on fiber properties (e.g., Mauney, 1992). These relations change over time, affecting bolls at different stages, depending on their date of differentiation. Until recently, the analysis of fiber quality was only possible for samples of a mass equivalent to several bolls. In 1993, Kerby grouped bolls by position to study fiber development as affected by source to sink relationships. The Uster Advanced Fiber Information System (AFIS) (Bradow *et al.*, 1997) permits the analysis of very small samples such as individual bolls to understand the dynamics of cotton production. This research targeted the quantification of the variability of fiber length and fineness at different scales: plot, plant, individual bolls at different positions and within a boll.

Material and Methods

This research was conducted in 1995 and 1996 on deep loams at CIRAD experimental station, Lavalette as part of several studies on cotton growth and development in the Mediterranean region. Two experiments were established, combining water stress and fertilizer N in 1995 and water stress, fertilizer N, plasticulture and plant growth regulators (PIX) in 1996. The cultivar was DES119 (*G. hirsutum*). Each plot consisted of 12 contiguous rows 12 meters in length. Five plots were used in 1995 and eight in 1996. Plots represented a range of treatments likely to affect the growth and development of the plant. Water was added at different, increasing frequencies (labelled 0,--,-, and +) depending on blooming date (before, after blooming). Fertilizer N varied from 0 (N0) to 120 kg/ha (N120) in the form of Urea applied as a side-dressing post-germination and at blooming. Table 1 describes the techniques applied on each of the 13 plots.

The numbers in the table indicate the number of plants/m² for each cell obtained by different inter-plant spacing with a fixed between row spacing of 0.8 m. Irrigation was applied using sprinklers distributed as a 9x9 m grid. Given the climatic conditions of the South of France, it was not possible to harvest all bolls initiated for the « + » water treatments after blooming. Therefore this type of treatment was not repeated in 1996, and was replaced by different quantities of post-blooming irrigation treatments.

On each of the plots, ten plants were randomly chosen and the bolls on the first position on the sympodia (fruiting branches) were individually labelled and collected. After ginning the sample with a mini-roller gin, the fiber properties of each boll were measured on an AFIS using two separate modules for length and maturity measurements in 1995 and a single two-functions module in 1996. Fineness variance is not available in 1996. Fiber from all carpels together was homogenized manually and the measurements were replicated on three strips in 1995 and four in 1996

(Clouvel *et al.*, 1997). A sample 'strip' thus consisted of a thousand fibers.

The statistical analysis targeted the estimation of effects due to different factors either fixed or due to the treatment, the boll position, the random choice of the plants within each plot and the random choice of strips within each boll. All these effects are assumed to add up to a linear model:

$$Y_{ijkl} = m + A_i + B_{ij} + C_k + (AC)_{ik} + (ABC)_{ijk} + D_{ijkl}$$

Where m is the intercept term, Ai is the combined effect of plot and treatment i, Bij is the random effect of the jth plant of plot i, Ck is the effect of boll position k, (AC)ik is the plant x position interaction, (ABC)ijk is the random plot x plant x position interaction and Dijk is the error effect e.g. the effect of strip l within position k of plant j of plot i.

All random effects are supposed to be Gaussian and independent from each other. Furthermore, the fact that some data may be missing must not depend on any effect. Therefore it is appropriate to eliminate positions where their presence cannot be considered a random event. This was the case with positions 4.1 and 5.1 that were absent from some plots. This is also the case for positions above main stem node 10 where the absence of bolls was linked to insufficient maturity on the post blooming « + » irrigated treatments in 1995 and on the rain-fed plot in 1996. The positions that were retained for analysis were from 6.1 to 10.1 inclusive. The same model applies to any mean characteristics and within strip variance (log-transformed) measured by AFIS. Normality of residuals was checked for each variable.

The statistical analysis targeted the identification of the variability due to each of the experimental scales in this study: plot, plant, boll, fiber samples (strips), and individual fibers within the sample. All these experimental units together formed a hierarchical study group with different levels, to each of these levels corresponds a random effect. Models parameters were estimated using the restricted maximum likelihood method (RFML) as implemented in SAS/STAT mixed procedure (Littell *et al.*, 1996). Heteroscedasticity was tested for each of the random effect using maximum restricted likelihood ratio test (SAS institute Inc, 1989). However, model was supposed homoscedastic for the log transformed within strip variances.

Results

The results are presented by discussing the variability assessed at each level (strip, boll, plant, plot) and then examining the potential mechanistic, agronomic, and future research implications of the observations.

The variability in yields (base 4 g/boll) was 1.8 to 4.4 t/ha with a strong dependence on irrigation in 1996 but also a strong effect of fertilizer N. In terms of the fiber quality produced, Figures 1 to 3 represent the variance (log transformed) as a function of the mean of the length and the lineal fineness for each of the strips. Examinations of the cloud of points obtained for 1995 and 1996 for all plots, confirms that the variance associated with fiber length attains a maximum for a mean fiber length of approximately 23 mm and then decreases as the mean length increases. The variance of fiber fineness results were available for 1995 only and confirm that for that year, the variance of this characteristic decreases as the mean increases. Table 4 summarizes the variability associated with each treatment in 1995 and 1996 for the component length and lineal fineness.

Variability between plants, boll positions and sample strips.

Using the means output given by AFIS for each strip, several dependence hypotheses were tested relative to plot effects on variance between plants, between positions (random effects), and within strips in a boll. For fiber length, the comparison of likelihood between the different hypotheses show a significant plot effect on the variance between strips whereas the variance between plants and positions is independent of the plot. For fiber fineness, the plot has no effect on any of the variances studied. The models associated with retained hypotheses were then applied to estimate means and variance values appearing in Table 3. Independent of the plot, a significant variance between plants exists that was estimated at 0.0119 and 0.7744 for the fiber length in 1995 and 1996, and 26.385 and 94 .167 for fiber fineness in 1995 and 1996, respectively.

The effect of the plot on the parameter means is highly significant in 1995 but not in 1996. The effect of boll position is highly significant for length. For fiber fineness it is significant only for 1996 (significant interaction plot x position in 1995).

Variability within the strip

The application of the homoscedastic model to the AFIS variance output at each strip level shows a very significant effect of the plot on the variance of the length and fineness measured within-strips in 1995 and '1996. The only effect of position found in 1996 was length variability in interaction with plot effect.

Discussion

Figures 1 to 3 show clouds of data with particular trends (within strip fiber variance as a function of the mean values). The existence of variable maximum for the length and the decreasing trend for fineness was confirmed by these studies. This observation is important for the determination of a theoretical model of elongation and maturation of a population of fibers within the boll. Based on these trends, the objective of minimizing the variability within the boll (whether in terms of length or fineness) is compatible with that of the largest mean value. The maximum overall mean is linked to the specific cultivar, however the nature of the variability is both genetic and environmental. This trend occurred for length variance in 1995 and 1996.

The maximum value of 23 mm for DES 119 could be a varietal characteristic. This observation requires confirmation in other cultivars.

The results of this research show that the fundamental variability is already present within the boll and the variability within the boll depends on the treatments. For positions 5-1 to 10-1, there was no significant variability between plants regardless of the year and the fiber quality parameters. There was a characterisable variability difference between positions (imposed on the model and verified on the fixed effects). It is this variability that is the object of the work most often presented: effect of position on the plant (Muhidong, 1995), and effect of crop ‘terminators’ on the maturity of the ‘top’ crop.

These results show that this approach must be examined in terms relative size of the intra-boll variability and variability between positions. For example, the variance between positions for fiber length in this research was estimated at 0.622 in 1995 and 0.930 in 1996 while variance between positions of fiber fineness was estimated at 26.385 in 1995 and 71.561 in 1996. While statistically significant, these variances do not have equivalent measurements for the variances observed within the bolls. Only the small bolls on the top part of the plant can compete. It is necessary to study in a parallel manner the effect of a technique not only on the variability between positions but on what occurs within the boll, otherwise there will always be a risk of no gain.

Variability within plants has begun to be treated in plant growth and development models (e.g., Jallas, 1998). With regard to between plant variances in this research, the inclusion of variability between plants may not be necessary for further fiber quality process introduction in plant growth models.

Another implication of the model of fiber quality determination is the dynamic interplay between the mechanisms of elongation and cell wall thickening of a population of fibers within the boll. Thus any potential explanation or model of fiber quality must include the variability and feedback between all relevant factors that lead to observed properties.

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Table 1. Experimental treatments (p = plasticulture).

	1995				1996				
	I(+,+)	I(0,+)	I(+,0)	I(+,-)	I(+,-)	I(+,-)	I(-,-)	I(-,--)	I(0,0)
N0			5.6			9	9		12
N30		5.6	5.6	9 p	9 p pix				
N90	5.6		5.6				9	12	
N120						9			

Table 2. Variability of fiber length and fineness for 1995 and 1996.

Plot 1995	Length			Fineness	
	Mean (mm)	Between strip variance	Within strip variance	Mean (mtex)	Within strip variance
I(+,+)N90	24.1	1.826	106.83	161.44	3052.25
I(+,0)N0	24.54	0.978	87.44	177.11	2509.23
I(+,0)N30	24.33	1.225	90.83	174.84	2686.11
I(+,0)N90	24.08	1.350	91.19	173.78	2658.61
I(0,+)N30	21.25	3.211	105.53	160.89	2736.38
Plot	*** (p=0.0001)		** (p=0.0038)	*** (p=0.0001)	*** (p=0.0001)
Position	*** (p=0.0011)		ns (p=0.5570)	ns (p=0.7019)	ns (p=0.6201)
Plot x pos.	ns (p=0.7898)		ns (p=0.9971)	* (p=0.0124)	ns (p=0.2654)
Plot 1996	Length			Fineness	
	Mean (mm)	Between strip variance	Within strip variance	Mean (mtex)	
I(+,-)p	24.58	0.780	94.16	172.15	
I(+,-)p pix	24.16	1.511	103.23	170.56	
I(+,-)N0	24.90	0.976	89.12	167.23	
I(+,-)N120	25.12	1.242	104.48	163.14	
I(-,-)N0	24.77	0.891	102.51	166.65	
I(-,-)N90	25.36	0.736	100.08	170.87	
I(-,--)N90	24.67	1.172	97.91	171.79	
I(0,0)N0	24.53	0.785	90.92	175.45	
Plot	ns (p=0.2654)		***(p=0.0001)	ns (p=0.2389)	
Position	*** (p=0.0001)		ns (p=0.5872)	*** (p=0.0001)	
Plot x pos.	ns (p=0.0500)		* (p=0.0340)	*** (p=0.0067	

Figure 1. Fiber length variability 1995.

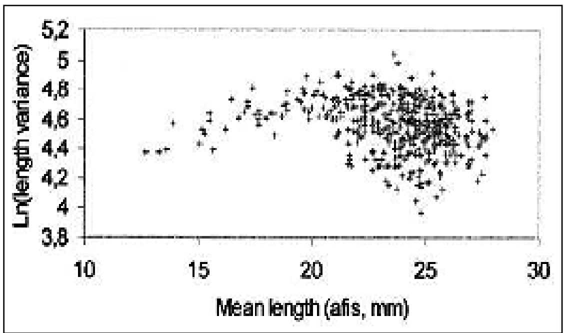

Figure 2. Fiber length variability 1996.

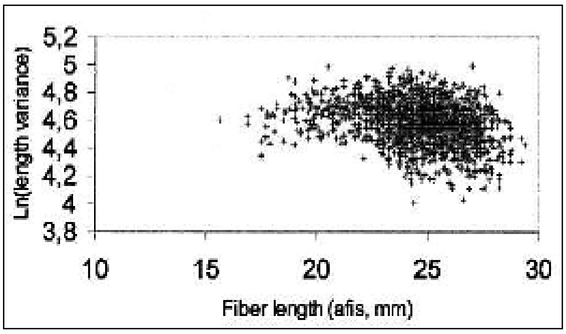

Figure 3. Fiber fineness variability 1995.