MODULATION OF ECONOMICALLY IMPORTANT COTTON FIBER PROPERTIES BY FIELD SPATIAL VARIABILITY

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Abstract

Cotton plant mapping, in which fiber properties and yield are quantified at the boll or field-block level, has revealed extensive modulation of fiber properties by the growth environment (Bradow, et al., 1997a; 1997b; 1997c). Use of the AFIS particle-sizer, which is capable of handling small fiber samples [*ca.* 200 to 10,000 fibers] from individual bolls and locules (Bradow et al., 1997a; 1997c), has made possible documentation of significant genotype responses to irrigation timing, amount, and method, planting and flowering date, and boll thermal microenvironment (Bradow et al., 1997b).

Those cotton fiber properties related to fiber maturity, *i.e.*, fiber cell-wall thickness, micronaire, and fiber cross-section, were particularly sensitive to the thermal environment described by accumulations of heat units above 15.5°C, the accepted lower temperature limit for cotton metabolism (Gipson, 1986). When fiber developmental rates were calculated on the basis of heat units, close linear relationships were found between fiber maturation rates and cumulative Growth Degree Days [GDD] with base temperature = 13.5°C and ceiling temperature = 32.0°C (Bradow et al., 1997b; Johnson et al., 1997). After day-length and insolation were added to this GDD model, 69% of the variation in Upland cotton fiber length was explained, despite fiber length being considered relatively insensitive to growth environment. This three-factor GDD model was even more successful in describing variability in immature fiber fraction, fiber cross-section, and micronaire, fiber properties for which the coefficients of determination were 80%, 71%, and 82%, respectively.

The studies on which these GDD models were based did not include soil properties. Therefore, a two-year experimental design incorporating site-specific mapping of soil spatial variability was begun in 1996 in a producer's field in South Carolina. This paper reports the preliminary [single year] correlations found among cotton fiber yield, the fiber properties of length, diameter, maturity, cross-section, micronaire, strength, and elongation, and the edaphic variables, soil water, organic matter, pH, cation exchange capacity, and the levels of phosphorus, sodium, potassium, calcium, and magnesium.

The cotton [*Gossypium hirsutum*] genotype was LA 887, which was grown in 1996 and 1997 in a producer's field near Florence, South Carolina. Four transects [>305 m] were run on the longest dimensions of the field sections (Bradow et al., 1998; Johnson et al., 1998). Within the larger section of the irregularly shaped field, a 122- x 38-m grid was mapped at 7.6-m intervals. The eastern side of the grid was coincident with the southern half of one transect, and the grid was characterized by a Carolina Bay landform in the southwest corner.

The soil samples taken along the transects and from the grid intervals were 0 to 20.3-cm cores. Soil tests included determination of soil water [%], organic matter [%], pH, phosphorus, sodium, potassium, calcium, magnesium [all ions, mg kg^{-1}], and cation exchange capacity [CEC, meq 100-g $^{-1}$]. The cotton crop was planted the first week in May, and production practices and inputs followed recommendations of the South Carolina Extension Service.

During the last week in October, cotton fiber samples were hand-harvested according to transect and grid maps and saw-ginned [without lint cleaner]. Yields were reported as 218-kg bales and as kg-lint ha^{-1}. The Zellweger Advanced Fiber Information System [AFIS A-2 particle-sizer] was used to quantify the following fiber properties: fiber length by number, short fiber content by number [% distribution of fibers <12.5 mm], fiber length by weight, short fiber content by weight [% distribution of fibers <12.5 mm], diameter by number, circularity [theta], immature fiber fraction [% distribution of theta <0.25], cross-sectional area by number, fine fiber fraction [% distribution of fiber with cross-section <60 lm^2], micronAFIS [AFIS micronaire analog], and perimeter (Bradow et al., 1997a; 19967c; 1998; Johnson et al., 1998). When an individual fiber sample was larger than 50 g, the HVI [High Volume Instrument] was used to determine fiber micronaire, bundle breaking strength [tenacity] and percent elongation (ASTM, 1994).

For all soil and fiber properties, simple statistics [means, standard deviations, coefficients of variation, range maximums and minimums] were calculated on the basis of total samples [grid plus transects] and grid samples only. Spatial variability maps were constructed from the grid soil and fiber (Johnson et al., 1998). Simple linear correlation analysis was used to examine interactions among the individual soil and fiber properties.

Soil properties along the transects and within the grid were highly variable. The southern section of the field contained elevated soil organic matter and soil phosphorus levels that were related to the presence of the Carolina Bay landform, which was typified by higher soil water content and

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flooding during periods of high rainfall. Soil CEC also varied so that there were two distinct bands of high CEC in the southern and middle sections of the field where soil organic matter and clay content were high.

The presence of the Carolina Bay landform in the grid skewed some soil properties. In the grid, the means for phosphorus and organic matter were four percent higher than the combined grid and transect means for those soil properties. Grid calcium and magnesium levels were more than seven percent lower than the corresponding combined means. The minimum values for all soil properties were found in the grid sample data. The maximum values for soil water, phosphorus, sodium, pH, organic matter, and CEC were also found in the grid soil sample data. The maximum values for potassium, calcium, and magnesium occurred in samples taken from the four transects.

The close correlations among soil organic matter, phosphorus, and pH are related to the presence of the Carolina Bay landform, which is seen as the highest concentration zone on the organic matter and phosphorus grid maps and the lowest pH zone on the soil pH grid map. The correlations among the cations, K, Ca, and Mg, were not affected by the presence of the Carolina Bay landform in the grid. Across the grid, variability was highest in phosphorus level and lowest in pH [based on standard deviation of the means].

Fiber properties of samples harvested along the transects and within the grid were less variable than were the soil properties based on the standard deviations of the individual means. Grid fiber-property means varied less than two percent from the corresponding combined transect and grid means. The minimum means of length by weight, short fiber content by weight, length by number, short fiber content by number, diameter, circularity, area, micronAFIS, perimeter, micronaire, bundle breaking strength, and elongation were all found in the grid samples. The maximum means of short fiber content by weight, length by number, immature fiber fraction, fine fiber fraction, perimeter, and bundle breaking strength were also found in samples from the grid section.

The correlations among fiber properties were grouped so that the simple 'fiber shape' characteristics [length, length distributions, and diameter] were highly correlated with each other. Strong correlations also existed among the 'fiber maturity' characteristics [circularity, cross-sectional area, and micronAFIS or micronaire]. Diameter was closely correlated with fiber circularity, cross-sectional area, and micronAFIS or micronaire. In the combined transect plus grid data, significant correlations existed between fiber bundle breaking strength and diameter [r = -0.250, p = 0.0059**], perimeter [r = 0.029, p = 0.0013**], cross-sectional area [r = -0.185, p = 0.043*], fine fiber fraction [r = +0.216, p = 0.018*], and micronaire [r = -0.223, p = 0.014*]. Since the same HVI/stelometer process is used to determine fiber bundle breaking strength and elongation percent, these fiber properties were also related in both the combined and grid only data.

Both maximum and minimum yields were found in the grid data, but the average grid yield was 760.5 kg ha^{-1}, and the combined transect plus grid yield average was 782.2 kg ha^{-1}. Yields in the grid were lowest to the north of the Carolina Bay zone and highest at the eastern edge of the grid. However, the yield mean of Transect 3, which ran tangentially to the grid, was 302.5 ± 456.1 kg ha^{-1}. The decreased yield and marked variability in yield along Transect 3 may be related to the elevated phosphorus levels along that transect, but Transect 3 phosphorus levels were not toxic. [Transect 3 mean phosphorus level was 195 ± 37.6 mg kg^{-1}, compared to the overall mean phosphorus level of 152.5 ± 103.6 mg kg^{-1} and the grid mean phosphorus level of 158.8 ± 116.9 mg kg^{-1}.] However, the 1997 site-specific data considered here do not include the weed-pressure or population-density information necessary for accurate diagnosis of the observed spatial variability in yield. The grid soil water map also suggests the presence of a significantly drier soil zone to the northwest along Transect 3.

Yield was positively correlated with soil pH [r = +0.433, p = 0.0001***]. Negative correlations [p = 0.0001***] were found between yield and phosphorus [r = -0.584], and yield and organic matter [r = -0.542]. Yield and soil water were also negatively correlated [r = -0.258, p = 0.002**] since the higher organic matter and supraoptimal soil water of the Carolina Bay landform reduced yield.

Among the combined grid and transect fiber properties, positive correlations with yield were found for short fiber content by number [r = +0.409, p = 0.0001***], short fiber content by weight [r = +0.336, p = 0.0001***], and immature fiber fraction [r = +0.191, p = 0.025*]. A negative correlation existed between yield and micronAFIS [r = -0.179, p = 0.037*], but that relationship did not appear between yield and micronaire data because the amounts of fiber harvested from low-yielding portions of the field were insufficient for HVI analysis. The small-sample requirement of AFIS did allow fiber from those low-yield points to be included in the micronAFIS [and other AFIS] determinations (Bradow et al., 1997c).

Fiber properties were quantified by three different methods, *i.e.*, the AFIS length and diameter module, the AFIS fineness and maturity module, and the HVI, which determined micronaire, bundle breaking strength, and percent elongation (Bradow, et al., 1997a; 1997c; 1998; Johnson et al., 1998). None of the correlations between the soil properties and the length and diameter group of fiber properties exceeded 0.500. However, the positive correlations between soil calcium and magnesium levels and fiber length on both number and weight basis indicate that site-specific application of lime *might* result in longer fiber and, thus, higher crop value. The positive effect of increased pH on fiber length by weight is also indicative of benefits to be gained from liming this field. These correlations also indicate minor increases in fiber length from added potassium. Further, additional phosphorus and organic matter might increase fiber diameter and reduce short fiber content. Only diameter was correlated with soil CEC [cation exchange capacity].

Although diameter is measured by the same AFIS A-2 module that quantifies fiber lengths and short fiber contents, this fiber property is intuitively and geometrically related to fiber cross-sectional area and circularity, properties which are measured by the AFIS fineness and maturity module (Bradow et al., 1997c). AFIS perimeter is calculated from area and circularity and is grouped with those fineness and maturity fiber properties. On the basis of the simple correlation analyses, fiber maturity, when quantified as circularity, immature fiber content, cross-sectional area, fine fiber fraction, or micronAFIS, could have been increased by the addition of phosphorus and/or organic matter. Soil amendments that lower soil pH would also have increased fiber maturity. Potassium, which has been recommended for increasing cotton fiber quality (Pettigrew, et al., 1996) had no significant effect on any of the fiber maturity properties (Bradow et al, 1998). The correlations between these fiber-maturity characteristics and soil properties were generally higher in the combined grid plus transect data than in the grid only data set. The exceptions were the slight increases in the correlation coefficients and significance of the comparisons between CEC and cross-sectional area and between CEC and micronAFIS in the grid only data.

The fiber properties, micronaire, bundle breaking strength, and percent elongation were measured by HVI, the instrument currently used in all USDA, Agricultural Marketing Service cotton classing offices. Acceptable HVI analyses require samples larger than 50 grams, and these HVI data, therefore, include a discernible bias against lower weight samples from the low-yielding portions of the grid and transects. The correlations between soil properties and HVI fiber properties show no useful or significant relationships between soil properties and increased fiber strength. Because the number of fibers in a yarn cross-section increases with increasing fiber fineness, a soil property that increases fine fiber fraction or decreases fiber diameter [for example, pH] *might* increase yarn strength. However, these HVI bundle breaking strength data indicate no direct relationships between soil properties and fiber, rather than yarn, strength.

Increased organic matter *might* decrease fiber elongation and, thereby, improve fiber-spinning properties. Increased soil CEC *might* result in increased HVI micronaire, probably by increasing fiber cross-section. However, soil modifications based on such weak correlations with fiber properties would be difficult to recommend to the grower. Within the grid, the correlations among soil properties and HVI fiber properties did not vary from those for the combined grid and transect data (Bradow et al., 1998; Johnson et al., 1998).

The appropriate weather data have not yet been integrated with the soil and fiber properties databases. Therefore, only the roughest site-specific recommendations to the grower can be formulated at this time. However, the simple statistics based were useful in preliminary interpretations of the grid maps and transect data (Bradow et al, 1998; Johnson et al., 1998). The occurrence and significance of correlations among soil and fiber properties may be the most interesting of the preliminary results since relationships between soil characteristics and cotton yields have been studied more often.

Beyond the described relationships between the edaphic environment and cotton yields or fiber properties, the preliminary results suggested some necessary or advantageous modifications of the methodology used in the first year of the study. Most importantly, additional soil water data should be collected during the growing season. The single soil-water data set collected soon after seedling emergence offered some information about the sites of potential waterlogging in the Carolina Bay landform and about which zones in the field dried most rapidly after a rainfall. Although a grower would know the general locations of dry or marshy portions of the field, the significant correlation between soil water and yield, in particular, suggests that additional site-specific mapping of soil water would be needed before recommendations could be made concerning irrigation or surface leveling. In the next-generation research application, soil water could be determined at planting or seedling emergence, near the beginning of the bloom period, at cutout, and, possibly, when harvest aids are applied at the termination of the growing season. Those research results may reveal that one or two soil water determinations during the growing season would be sufficient.

In addition, population-density data should be gathered when the pre-bloom soil samples are collected. Estimates of weed and herbivore pressures should also be made at the beginning of the bloom period and when soil samples are collected around the time of cutout. Remote sensing should be useful in making estimates of both pest pressures and stand population density. However, cotton is normally grown as a closed canopy not penetrated by remote sensors, and soil sampling will remain the method of choice for soil water determinations.

Finally, the simple correlations between soil properties and fiber characteristics in a single field and year that are reported here indicate that the more powerful analytical techniques of Precision Agriculture can elucidate the complex plant-environment interactions that underlie both fiber yield and quality in cotton. Multi-year site-specific databases integrated with the corresponding environmental data will provide valuable site-specific recommendations for a grower whose field has been mapped and also serve as the basis for generalized improvements in cotton production.

Disclaimer: *Trade names are necessary for factual report of data and do not indicate USDA guarantee, warranty, or approval.*

References

American Society of Testing and Materials. 1994. Standard test methods for measurement of cotton fibers by high volume instruments (HVI). Annual Book of ASTM Standards, 07.02: ASTM Standard D 4604-86, pp. 475-485; ASTM Standard D 4605-86, pp. 486-494.

Bradow, J.M., P.J. Bauer, O. Hinojosa, and G.F. Sassenrath-Cole. 1997a. Quantitation of cotton fibre-quality variations arising from boll and plant growth environments. Eur. J. Agron. 6:191-204.

Bradow, J.M., P.J. Bauer, G.F. Sassenrath-Cole, and R.M. Johnson. 1997b. Modulations of fiber properties by growth environment that persist as variations of fiber and yarn quality. Proceedings 1997 Beltwide Cotton Conf., pp. 1351-1360.

Bradow, J.M., L.H. Wartelle, P.J. Bauer, and G.F. Sassenrath-Cole. 1997c. Small-sample cotton fiber quality quantitation. J. Cotton Sci. 1:48-58.

Bradow, J.M., R.M. Johnson, P.J. Bauer, and E.J. Sadler. 1998. Modulation of economically important cotton fiber properties by field and spatial variability. Proceedings, 4th International Conference on Precision Agriculture. In press.

Gipson, J.R. 1986. Temperature effects on growth, development, and fiber properties. p. 47-56. *In*: J.R. Mauney and J. McD. Stewart (ed.) Cotton physiology, The Cotton Foundation, Memphis, TN.

Johnson, R.M., J.M. Bradow, and G.F. Sassenrath-Cole. 1997. Modeling of cotton fiber quality from environmental parameters. Proceedings, 1997 Beltwide Cotton Conf., pp. 1454-1455.

Johnson, R.M., J.M. Bradow, P.J. Bauer, and E. J. Sadler. 1998. Spatial variability of cotton fiber yield and quality in relation to soil variability. Proceedings, 4th International Conference on Precision Agriculture. In press.

Pettigrew, W.T., J.J. Heitholt, and W.R. Meredith, Jr. 1996. Genotypic interactions with potassium and nitrogen in cotton of varied maturity. Agron. J. 88:89-93.