Zoned Management of Cotton Fiber Yield and Quality

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Genotype is an important factor in determining some fiber properties, but environmental variations are the chief determinants of micronaire, color, and uniformity. In a 1996-97 study of Upland cotton grown in SC, spatial variations in soil pH and the levels of P, Na, Ca, Mg, or % organic matter modulated fiber properties, including micronaire and color. Higher P and %OM levels were associated with increased maturity and micronaire and with decreased fiber yellowness and increased fiber whiteness, modifications desirable in cotton fiber. Higher soil K also improved fiber whiteness. Increased soil pH and Ca and Mg were negatively correlated with micronaire and maturity, and soil P and %OM were negatively correlated with yield in both years. These relationships were described by simple correlation statistics, but geostatistics are even more useful for mapping and resolving spatial interactions among soil and fiber properties and for realizing the predictive potential of zoned management. Although preliminary, site-specific maps suggest practical strategies by which zoned management of cotton production can increase the end-use value of the cotton and, thus, the economic return to the producer and processor.

Keywords: zoned management, cotton fiber, crop quality, soil spatial variability

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 1997 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.

MATERIALS AND METHODS

The cotton [*Gossypium hirsutum*] genotype was LA 887, which was grown in 1997 and 1998 in a producer's field near Florence, South Carolina. Four transects [>305 m] were run as shown in Figure 1.

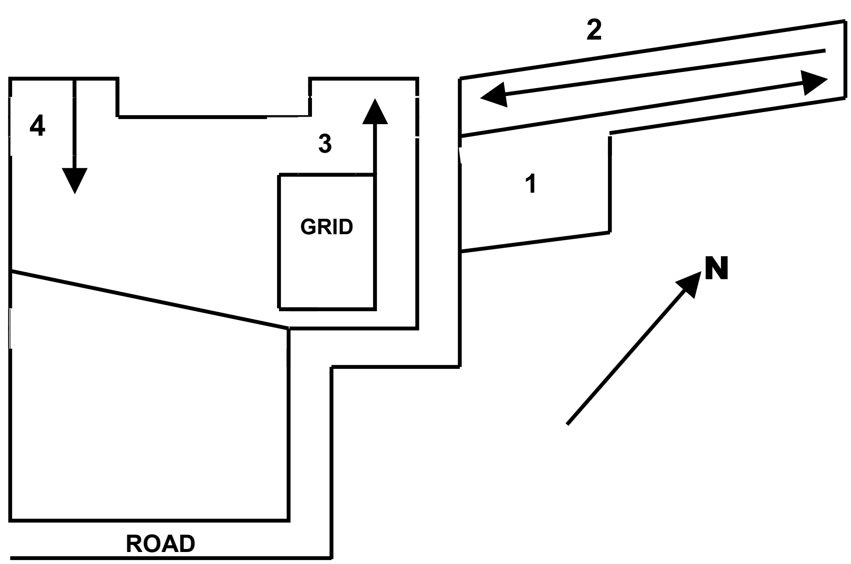

Figure 1. Location of Transects 1, 2, 3, and 4 [>305 m] and grid [122 x 38 m with 7.6 x 7.6-m intervals]. Producer's cotton field, Florence, SC, 1996.

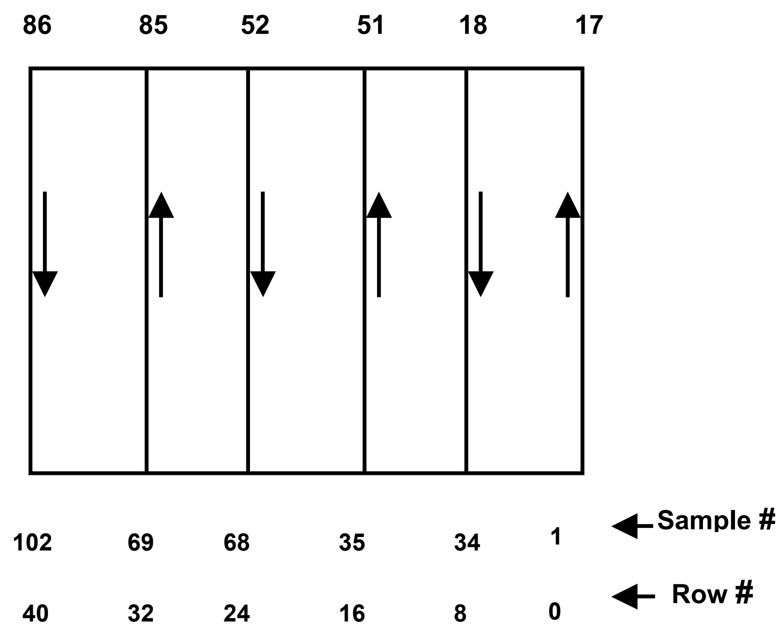

Figure 2. Map of 122- x 38-m grid showing direction of mapping, number of rows per grid interval and number of samples per grid section.

Within the larger section of the irregularly shaped field in Figure 1, a 122- x 38-m grid was mapped at 7.6-m intervals as shown in Figure 2. The eastern side of the grid was coincident with the southern half of Transect 3, 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. Yields were reported as 218-kg bales and as kg-lint ha^{-1}. The Zellweger Advanced Fiber Information System [AFIS 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 ③m^2], micronAFIS [AFIS micronaire analog], and perimeter (Bradow et al., 1997a; 19967c). 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 data and are discussed elsewhere in this volume (Johnson et al., 1999). Simple linear correlation analysis was used to examine interactions among the individual soil and fiber properties.

RESULTS AND DISCUSSION

Variability in soil 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 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 soil property means and standard deviations of the 141 core samples are shown in Table 1 with the minimum to maximum range for each property.

Table 1. Means, standard deviations, and maximum-minimum range of combined transect and internal grid soil properties.

Soil Property	Mean ±Standard Deviation	Minimum	Maximum
Soil Water	19.4 ±3.5 %	7.4%	38.1%
Organic Matter	0.83 ± 0.48 %	0.28%	2.25%
pH	5.3 ± 0.5	4.3	6.2
P	152.5 ± 103.6 mg kg^{-1}	38.0 mg kg^{-1}	436.0 mg kg^{-1}
K	146.8 ± 47.8 mg kg^{-1}	67.0 mg kg^{-1}	329.0 mg kg^{-1}
Na	6.14 ± 2.0 mg kg^{-1}	1.0 mg kg^{-1}	12.0 mg kg^{-1}
Ca	240.4 ± 95.8 mg kg^{-1}	101.0 mg kg^{-1}	604.0 mg kg^{-1}
Mg	52.9 ± 19.5 mg kg^{-1}	20.0 mg kg^{-1}	127.0 mg kg^{-1}
CEC	1.7 ± 0.5 meg 100-g^{-1}	0.6 meg 100-g^{-1}	3.0 meg 100-g^{-1}

The presence of the Carolina Bay landform in the grid skewed some soil properties from the combined transect plus grid means in Table 1. 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 listed in Table 1 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 strongest correlations [*r* > 0.500 and *p* > 0.990] among soil properties from the combined transects plus grid data are indicated by the **bold** type in Table 2.

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 darkest [highest concentration] zone on the organic matter and phosphorus grid maps and the lightest [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].

Table 2. Simple [Pearson's] correlation coefficients and significance levels among soil properties of transect and grid samples combined.

Soil Property	Organic Matter	pH	P	K	Na	Ca	Mg	CEC
	Correlation coefficient, *r*							
Soil Water	0.393 ***	-0.223 **	0.381 ***	0.343 ***	0.098	0.270 *	0.200 *	0.172 *
Organic Matter		**-0.679** ***	**0.904** ***	0.293 ***	0.227 **	0.094	-0.026	0.269 **
pH			**-0.743** ***	0.080	0.057	0.458 ***	0.494 ***	-0.117
P				0.099	0.153	-0.068	-0.217 **	0.300 ***
K					0.311 ***	**0.772** ***	**0.774** ***	0.385 ***
Na						0.407 ***	0.396 ***	0.230 **
Ca							**0.867** ***	0.315 ***
Mg								0.239 **

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Variability in fiber properties

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. The fiber property means, standard deviations, maximums, and minimums for the combined transect and grid samples are shown in Table 3.

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

Table 3. Means, standard deviations, maximums and minimums of fiber length, short fiber content, diameter, circularity, immature fiber fraction, area, fine fiber fraction, micronAFIS, micronaire, perimeter, breaking strength, and elongation from combined transect and grid samples.

Fiber Property	Mean ± Standard Deviation	Minimum	Maximum
Length By Weight	23.7 ± 0.72 mm	21.8 mm	25.64 mm
Short Fiber Content by Weight	8.8 ± 1.0 %	6.8 %	11.8 %
Length by Number	19.7 ± 0.6 mm	18.0 mm	21.3 mm
Short Fiber Content by Number	23.1 ± 2.0 %	18.5 %	28.2 %
Diameter by Number	13.3 ± 0.7 μm	11.6 μm	15.3 μ
Circularity, θ	0.464 ± 0.022	0.405	0.524
Immature Fiber Fraction	14.3 ± 2.1 %	9.2 %	21.0 %
Area by Number	107.4 ± 7.0 ③m^2	89.5 ③m^2	126.8 ③m^2
Fine Fiber Fraction	17.8 ± 3.7 %	9.1 %	28.6 %
MicronAFIS	3.818 ± 0.385	2.780	4.938
Perimeter	53.9 ± 1.0 ③m	51.1 ③m	57.3 ③m
Micronaire [HVI]	3.836 ± 0.374	3.000	4.800
Breaking Strength	25.9 ± 1.2 g tex^{-1}	23.3 g tex^{-1}	28.6 g tex^{-1}
Elongation	7.4 ± 0.5 %	6.0 %	8.5 %

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.

Variability in fiber yields

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).

Simple correlations among soil and fiber properties

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). Therefore, the soil properties are compared to the fiber properties in three separate tables, *e.g.*, Table 4 [AFIS length and diameter module], Table 5 [AFIS fineness and maturity module], and Table 6 [HVI data].

In Table 4, 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 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.

Table 4. Simple [Pearson's] correlation coefficients and significance levels among soil properties and AFIS fiber length and diameter properties from transect and grid data combined.

	Fiber Property from AFIS Length and Diameter Module				
Soil Property	Length by number	Short fiber content by number	Length by weight	Short fiber content by weight	Diameter by number
	Correlation coefficient, *r*				
Soil Moisture	0.041	-0.215 *	-0.072	-0.177 *	-0.003
Organic Matter	0.041	-0.355 ***	-0.188 *	-0.235 **	0.291 ***
pH	0.218 **	0.189 *	0.429 ***	0.053	-0.264 **
CEC	-0.065	-0.067	-0.136	-0.022	0.284 ***
P	0.017	-0.375 ***	-0.221	-0.257 **	0.340 ***
K	0.212 *	-0.186 *	0.155	-0.202 *	-0.040
Na	0.183 *	-0.181 *	0.121	-0.182 *	0.036
Ca	0.408 ***	-0.207 *	0.411 ***	-0.286 ***	-0.016
Mg	0.334 ***	-0.112	0.378 ***	-0.190 *	-0.186 *

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

These correlations indicate minor increases in fiber length from added potassium. Also, additional phosphorus and organic matter might increase fiber diameter and reduce short fiber content. Of the fiber properties in Table 4, only diameter was correlated with soil CEC [cation exchange capacity].

Although diameter is measured by the same AFIS 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 included in Table 5 with those fineness and maturity fiber properties.

On the basis of the correlations in Table 5, 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

Table 5. Simple [Pearson's] correlation coefficients and significance levels among soil properties and AFIS fiber fineness and maturity properties from transects and grid combined.

Soil Property	Fiber properties from AFIS fineness and maturity module					
	Circularity	Immature Fiber Fraction	Cross-Sectional Area	Fine Fiber Fraction	micronAFIS	Perimeter
	Simple correlation coefficient, *r*					
Soil Water	0.023	-0.058	0.005	-0.010	0.019	-0.024
Organic Matter	0.228 **	-0.293 ***	0.305 ***	-0.263 **	0.287 ***	0.232 **
CEC	0.147	-0.198 *	0.265 **	-0.254 **	0.217 *	0.269 **
pH	-0.214 *	0.286 ***	-0.282 ***	0.274 **	-0.268 **	-0.218 *
P	0.291 ***	-0.335 ***	0.364 ***	-0.307 ***	0.353 ***	0.257 **
K	0.022	-0.061	-0.021	0.015	0.002	-0.072
Na	0.067	-0.090	0.052	-0.037	0.064	0.001
Ca	0.048	-0.059	0.001	0.021	0.024	-0.069
Mg	-0.029	0.031	-0.152	0.148	-0.097	-0.229 **

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

maturity properties listed in Table 5. 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 relationships between soil properties and the HVI fiber properties are shown in Table 6.

The correlations between soil properties and HVI fiber properties show that there are 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 [pH in Tables 4 and 5] 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 (Table 5). However,

Table 6. Simple [Pearson's] correlation coefficients and significance levels among soil properties and HVI fiber properties from transects and grid combined.

Soil Property	Micronaire	Bundle Breaking Strength	Bundle Elongation Percent
	Correlation coefficient, *r*		
Soil Moisture	-0.008	-0.039	-0.069
Organic Matter	0.119	-0.048	-0.234 **
pH	0.011	-0.025	0.140
CEC	0.315 ***	-0.038	-0.039
P	0.158	-0.065	-0.215 *
K	0.121	0.019	0.040
Na	0.165	-0.027	0.062
Ca	0.125	-0.018	0.143
Mg	0.126	0.059	0.051

*, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

soil modifications based on these 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 reported in Table 6 for the combined grid and transect data.

Conclusions

The 1997 soil and fiber samples are not yet analyzed and the appropriate weather data have not yet been integrated with the 1996 soil and fiber properties databases. Therefore, only the roughest site-specific recommendations to the grower could be formulated at this time. However, the simple statistics based on the 1996 data were useful in preliminary interpretations of the grid maps and transect data. 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 1996 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 should 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.

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