Spatial Variability of Cotton Fiber Yield and Quality in Relation to Soil Variability

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ABSTRACT

Cotton fiber quality is important to the producer because reduced quality results in a significant monetary penalty. Therefore, to maximize profitability, the producer must also attempt to control the quality of the crop while maximizing yield. The tools of precision agriculture appear to be well suited to this task. The objective of this research was to measure the natural variability present in cotton fiber yield and quality parameters. Cotton, variety LA 887, was grown in a producer's field in Florence SC for two consecutive years. Soil (0–20 cm) and fiber samples (1 m row) were collected from a regular grid (120 * 40 m, 7.5-m interval). Soil properties determined included soil moisture, soil texture, organic matter, pH, Ca, Mg, K, P, and Na. Fiber quality was estimated by several methods, including the high volume instrumentation (HVI) method and the advanced fiber information system (AFIS). The HVI method is used by USDA–AMS to class and price cotton and the AFIS system is used primarily by cotton researchers. All fiber and soils data were analyzed by both conventional statistics (univariate and correlation) and geostatistical techniques (variogram analysis and kriging). Soils data was found to be non-normally distributed and spatially correlated. Fiber yield was normally distributed and spatially correlated and fiber quality varied in both its distribution and spatial correlation. Soil pH, soil phosphorus and soil organic matter were correlated with fiber yield and a number of fiber properties, including micronafis, immature fiber fraction (IFF), fine fiber fraction (FFF), cross-sectional area (An) and micronaire. Kriged maps of soil properties provided useful indicators of fiber yield and quality variation.

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INTRODUCTION

Despite increases in yields and market prices, U.S. cotton growers have experienced negative returns above total economic costs in almost every year since 1980 (USDA, 1992; Larson & Meyer, 1996). During that period, a significant percentage of total producer income from cotton has come from Federal loan programs and deficiency payments. Under the provisions of the FAIR Act of 1996, Federal commodity program deficiency payments will be phased out over the next seven years. Consequently, the full responsibility for price–income and risk management will fall directly to U.S. cotton growers. Thus, the economic survival of U.S. cotton producers will be determined by how rapidly and successfully improved cotton production technologies and cost efficiencies can be developed and adopted.

Precision Agriculture [PA] is an information and technology based agricultural management system that identifies, analyzes, and manages site spatial and temporal variability within fields for optimum profitability, sustainability, and protection of the environment (Robert et al., 1995, 1996). Only recently have PA systems shown potential for use in cotton production (Smith, 1996; Wilkerson & Hart, 1996). The PA approach to cotton production is an engineered system in which cultural inputs are made on a 'need basis' in a site-specific system that micro-manages spatial and temporal variability through mapping and integration of soil and plant data (Smith, 1996). It was the objective of this research to measure soil variability in relation to both cotton fiber yield *and* quality in a field under commercial production.

MATERIALS AND METHODS

A field experiment was conducted in a producer's field in Florence, SC to investigate the influence of soil spatial variability on the variability of cotton [*Gossypium hirsutum*, genotype LA 887] fiber yield and quality. Soil (0–20 cm) and fiber (1 m row) were collected from a regular grid (120 * 40 m, 7.5 m interval). The grid location was chosen to include a Carolina Bay landform to assure a significant range in soil and fiber variability. Soil properties determined included soil moisture (%), organic matter (%), pH, Ca, Mg, K, P, Na (all ions, mg kg^{-1} soil), and cation-exchange capacity (CEC, meq 100 g^{-1} soil).

Cotton fiber samples were collected, by hand, from ~1 m of row centered on the grid points in October. Fiber was saw ginned and weighed to determine yield (218 kg bales). The bulk fiber samples were then subsampled to determine fiber quality. Two methods were employed to evaluate fiber quality, the Zellweger advanced fiber information system (AFIS) was used on all samples and the high volume instrumentation (HVI) method was used when the fiber sample weight was ≥50 g. Fiber properties determined by the AFIS system included, fiber length by number and weight, short fiber content (% distribution of fibers < 12.5 mm) by weight and number, 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 μm^2), micronAFIS (micronaire analog) and perimeter. Properties determined by the HVI method include micronaire, elongation, leaf grade (a measure of leaf residue in the fiber), and color as estimated by the degree of reflectance (Rd) and yellowness (+b).

All fiber and soils data were analyzed by both conventional univariate statistics (SAS PROC UNIVARIATE) and variogram analysis (GeoEas). Prior to variogram analysis the spatial data was detrended by fitting a plane surface through each data set (SAS PROC REG), evaluating the surface at each data point and subtracting the surface from the raw data (Sadler et al., 1998). Simple correlation analysis was performed between soil and fiber properties on the combined two-year data set with SAS PROC CORR. Finally, spatial maps were constructed by kriging (Surfer) using the previously determined variograms.

RESULTS AND DISCUSSION

Soil Variability

Univariate Statistics

Soil-property data from the 1996-growing season is presented in Table 1. All soil properties, with the exception of sodium, exhibited a non-normal distribution, as determined from the Shapiro-Wilkes statistic (data not shown). The majority of these properties also exhibited a positive skew with the mean greater than the median (exception pH). Soil pH exhibited a slight, but measurable negative skew. These combined observations further support the non-normality of the 1996 soils data.

The coefficient of variation for the properties measured ranged from 9.1% for pH to almost 74% for soil phosphorus (Table 1).

Table 1. Univariate statistics of soil properties in 1996.

Soil property	N	Mean	Median	SD	CV	Skew
Soil moisture (%)	102	19.7	18.9	3.9	19.7	2.1
Phosphorus (mg kg^{-1})	102	158.8	111.4	116.8	73.6	1.0
Sodium (mg kg^{-1})	102	5.9	5.9	1.9	31.7	0.40
Potassium (mg kg^{-1})	102	142.9	139.4	45.2	31.7	0.30
Calcium (mg kg^{-1})	102	217.3	205.4	73.3	33.7	0.61
Magnesium (mg kg^{-1})	102	49.5	46.3	16.1	32.5	0.86
Soil pH	102	5.2	5.3	0.48	9.1	-0.33
Organic matter (%)	102	0.86	0.6	0.54	62.8	1.2
CEC (meq 100 g^{-1})	102	1.6	1.5	0.57	35.8	0.38

Soil properties data from the 1997 growing season are presented in Table 2. During this growing season all soil properties were non-normally distributed, as determined from the Shapiro-Wilkes statistic (data not shown). As with the 1996 data, these properties exhibited a positive skew with the mean greater than the median (exception pH). Soil pH exhibited a slight, but measurable negative skew.

The coefficients of variation for the 1997 data set were very similar to the 1996 data set with the CV ranging from 10 % for pH to almost 74% for soil phosphorus (Table 2). This range of variability also would suggest that there exists a sufficient range in the soil properties measured to benefit from a site-specific management strategy.

Table 2. Univariate statistics of soil properties in 1997.

Soil property	N	Mean	Median	SD	CV	Skew
Soil moisture (%)	102	9.1	8.5	1.9	21.0	1.1
Phosphorus (mg kg^{-1})	102	161.8	109.5	119.3	73.7	1.1
Sodium (mg kg^{-1})	102	6.3	6.1	1.9	30.6	0.82
Potassium (mg kg^{-1})	102	145.4	140.6	45.0	31.0	0.37
Calcium (mg kg^{-1})	102	251.4	242.9	78.8	31.3	1.1
Magnesium (mg kg^{-1})	102	56.3	50.6	18.2	32.4	0.52
Soil pH	102	5.0	5.1	0.53	10.6	-0.22
Organic matter (%)	102	0.82	0.5	0.50	61.1	1.3
CEC (meq 100 g^{-1})	102	2.1	2.0	0.60	28.4	0.55

Spatial Variability

The soil properties variogram analysis from the 1996 and 1997 growing season is presented in Table 3. All soil properties were spatially correlated, with the exception of soil pH. Note that all semivariogram models obtained did not exhibit a nugget effect. The semivariogram for soil moisture was linear in 1996 and spherical in 1997. In addition, the range of spatial correlation decreased from 106 to 40 m. Semivariogram models for P, Na, K, Ca, and Mg were similar in both 1996 and 1997. The range of spatial correlation also was similar, although decreasing slightly from 1996 to 1997. The semivariograms for soil organic matter and CEC were similar in range from 1996 to 1997, although the model changed from spherical to gaussian.

Table 3. Semivariance parameters of soil properties.

	1996		1997	
Soil property	Model	Range (m)	Model	Range (m)
Soil moisture (%)	L	106	S	40
Phosphorus (mg kg^{-1})	G	56	G	56
Sodium (mg kg^{-1})	E	30	E	27
Potassium (mg kg^{-1})	G	30	G	27
Calcium (mg kg^{-1})	G	30	G	27
Magnesium (mg kg^{-1})	G	30	G	27
Soil pH	NS†	NS	NS	NS
Organic matter (%)	S	46	G	46
CEC (meq 100 g^{-1})	S	27	G	27

† NS, not spatially correlated.

Fiber Variability

Univariate Statistics

Fiber yield and quality data from the 1996 growing season is presented in Table 4. The yield data was normally distributed, with the mean in good agreement to the median. The CV, however, was significant (52.3%), reflecting the large range in the data. The majority of the fiber properties examined also were normally distributed. The exceptions were L(n), L(w), Theta, FFF Elongation and Leaf grade. The data for L(n) and FFF were positively skewed, while L(w), Theta, elongation and leaf grade all had negative skews.

Table 4. Univariate statistics of fiber properties in 1996.

Fiber property	N	Mean	Median	SD	CV	Skew
Yield (Bales)	102	1.58	1.55	0.83	52.3	0.33
L(w)	100	0.93	0.90	0.04	4.7	1.17
SFC(w)	100	8.9	8.8	0.97	10.9	0.19
L(n)	100	0.79	0.80	0.03	3.8	-2.7
SFC(n)	100	23.1	22.9	1.9	8.3	-0.07
D(n)	100	13.3	13.3	0.63	4.7	-0.22
Theta	100	0.47	0.50	0.04	9.3	-1.11
IFF	100	14.5	14.5	2.1	14.8	0.36
A(n)	100	106.8	107.0	6.7	6.3	-0.11
FFF	100	18.2	17.9	3.7	20.2	0.80
Micronafis	100	3.8	3.8	0.39	10.3	-0.01
Perimeter	100	53.9	53.9	0.97	1.8	0.02
Micronaire	85	3.8	3.8	0.35	9.2	-0.10
Elongation	85	6.3	6.3	0.25	4.0	-0.45
Leaf grade	85	3.3	3.0	1.37	40.9	-0.07
Rb	85	76.9	76.9	1.73	2.3	-0.14
+b	85	8.8	8.8	0.61	6.9	0.43

The coefficient of variation for the fiber properties measured ranged from 1.8% for perimeter to almost 41% for leaf grade (Table 4). The properties with the highest variability were leaf grade, FFF, IFF, SFC(w), MicronAFIS and micronaire, with CVs of 40.9, 20.2, 14.8, 10.9, 10.3, and 9.2%, respectively.

Fiber yield and quality data from the 1997 growing season is presented in Table 5. As with the 1996 growing season the yield data was normally distributed, with the mean close to the median. The CV, although reduced from 1996 (43.0%), was still significant. The majority of the fiber properties examined also were normally distributed. The exceptions were L(n), L(w), Theta, Elongation, and Leaf grade. The data for L(n) and leaf grade were positively skewed, while Theta, and elongation had slight negative skews. Data for L(n) was not skewed.

The coefficient of variation for the fiber properties measured ranged from 1.7% for perimeter to 53% for leaf grade (Table 5). It should be noted that the fiber properties with the highest variability were identical to those noted in the 1996 growing season. Leaf grade, FFF, IFF, MicronAFIS, SFC(w), and micronaire, again exhibited the highest variability with CVs of 53.4, 21.0, 20.2, 13.2, 11.3, and 10.1%, respectively. These fiber properties are all strongly influenced by environmental variations and may benefit from site specific management techniques.

Table 5. Univariate statistics of fiber properties in 1997.

Fiber property	N	Mean	Median	SD	CV	Skew
Yield (Bales)	101	1.3	1.4	0.57	43.0	0.29
L(w)	101	0.94	0.90	0.05	5.2	0.39
SFC(w)	101	7.8	7.8	0.88	11.3	0.22
L(n)	101	0.80	0.80	0.02	3.0	0.0
SFC(n)	101	20.9	21.1	1.7	7.9	0.11
D(n)	101	13.5	13.6	0.59	4.3	0.39
Theta	101	0.48	0.5	0.05	10.4	-0.39
IFF	101	12.8	12.9	2.6	20.2	0.10
A(n)	101	110.6	110.0	7.8	7.0	0.39
FFF	101	15.5	15.6	3.3	21.0	0.21
Micronafis	101	4.1	4.0	0.54	13.2	0.37
Perimeter	101	53.9	53.8	0.90	1.7	0.32
Micronaire	79	4.0	3.9	0.40	10.1	0.25
Elongation	79	6.6	6.6	0.35	5.3	-1.13
Leaf grade	79	2.6	3.0	1.40	53.4	0.16
Rb	79	76.5	76.5	1.61	2.1	-0.36
+b	79	9.6	9.6	0.59	6.1	0.22

Spatial Variability

The yield and fiber properties variogram analysis from the 1996 and 1997 growing season is presented in Table 6. The semivariogram models that were fit to the yield and fiber data did not exhibit nugget effects. Cotton yield was spatially correlated in both the 1996 and 1997 growing seasons with exponential semivariograms. The range of spatial correlation decreased slightly from 30 m in 1996 to 27 m in 1997. The majority of the fiber properties determined were also spatially correlated. The exceptions were L(n), SFC(n), Rb and +b in 1996 and L(w), L(n), SFC(w), SFC(n) and Theta in 1997. The exponential model fit the majority of the fiber properties in both 1996 and 1997. The exceptions in 1996 were SFC(w) and perimeter, which were fit to the linear model and IFF which was described by the spherical model. In 1997 all properties were described by the exponential model, with the exception of +b, which was gaussian. The range of spatial correlation was similar in both growing seasons, with most properties correlated between 15 and 30 m. The notable exceptions were perimeter and SFC(w) in 1996 which had ranges of 106 and 91 m, respectively and +b in 1997 which had a range of 43 m.

Table 6. Semivariance parameters of fiber properties.

	1996		1997	
Fiber property	Model	Range (m)	Model	Range (m)
Yield (Bales)	E	30	E	23
L(w)	E	27	NS†	NS
SFC(w)	L	91	NS	NS
L(n)	NS	NS	NS	NS
SFC(n)	NS	NS	NS	NS
D(n)	E	27	E	23
Theta	E	24	NS	NS
IFF	S	18	E	18
A(n)	E	24	E	20
FFF	E	24	E	15
Micronafis	E	18	E	18
Perimeter	L	106	E	15
Micronaire	E	15	E	14
Elongation	E	15	E	14
Leaf grade	E	15	E	14
Rb	NS	NS	E	33
+b	NS	NS	G	43

† NS, not spatially correlated.

Relation between Soil and Fiber Variability

Correlation Analysis

Results from the correlation analysis between soil and fiber properties from the combined 2-yr data set are presented in Table 7. Fiber yield was significantly correlated to soil P, organic matter, pH, and CEC. The negative correlation to P and OM is related to the increase in these properties in the Carolina Bay present in the field. This part of the field was subject to flooding during periods of high rainfall, resulting in significant decreases in yield. The soil pH also was lower in this region, accounting for the significant positive correlation. The best predictor of fiber length appears to be soil moisture, with the negative correlation indicating that shorter more immature fibers will occur in the wetter parts of the field.

Table 7. Simple (Pearson's) correlation coefficients between soil and fiber properties for combined (1996 and 1997) data set.

Fiber	Moist.	P	Ca	Mg	pH	OM	CEC
Yield		-0.51***	ns	ns	0.46***	-0.50***	-0.17*
L(w)	-0.16*	-0.19**	0.21**	0.21**	0.21**	-0.16*	ns
SFC(w)	0.40***	ns	-0.28***	-0.23	ns	ns	-0.26***
L(n)	-0.15	ns	ns	ns	ns	ns	ns
SFC(n)	0.39***	ns	-0.26***	-0.21**	ns	ns	-0.31***
D(n)	ns	0.36***	-0.15*	-0.28***	-0.46***	0.32***	ns
Theta	ns	0.25***	-0.17*	-0.19**	-0.33***	0.19**	ns
IFF	0.23***	-0.36***	ns	0.15*	0.48***	-0.30***	ns
A(n)	-0.17*	-0.40***	-0.16*	-0.25***	-0.51***	0.34***	ns
FFF	0.28***	-0.31***	ns	0.20**	0.45***	-0.25***	ns
Micronafi	-0.17*	0.40***	ns	-0.20**	-0.51***	0.32***	ns
Perimeter	ns	0.14*	ns	-0.22**	-0.17*	0.15*	ns
Micronair	ns	0.22**	ns	ns	-0.26***	0.17*	ns
Elongatio	-0.44***	-0.21**	ns	0.16*	ns	-0.17*	0.28***
Leaf	0.17*	-0.19*	ns	ns	0.17*	-0.18*	ns
Rb	0.21**	0.37***	ns	ns	-0.26***	0.42***	ns
+b	ns	ns	0.19*	0.19*	ns	ns	0.21***

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

Diameter was best described by soil pH and P. Theta, IFF, A(n), FFF, and micronafis are all related to fiber maturity and exhibited similar responses to soil variation. The best predictors for these properties appear to be soil pH, followed by soil P and organic matter. Soil moisture and soil Mg also influence these properties, but to a lessor extent. Soil properties determined by the HVI method include micronaire, elongation, leaf grade, Rd and +b. These properties also are correlated to soil pH, soil P and soil organic matter. Fiber yellowness showed a different response with significant correlations to soil Ca, Mg, and CEC. These combined observations would suggest that fiber yield and quality was lower in the

Carolina Bay portion of the field where the soil moisture was greater and pH lower. A potential benefit to both yield and quality would be realized if this part of the field were limed and drained. These relations become clearer in the field maps presented in the next section.

Soil and Fiber Maps

Selected soil, yield and fiber property maps are presented in Fig. 1 and 2. The relation between soil moisture and yield are clearly illustrated in Fig. 1. The Carolina Bay present in the lower right of both maps possesses the highest soil moisture and also the lowest yield. A similar correspondence is seen between soil pH and micronafis in Fig. 2. Additional fiber and soil maps could be used to further study the spatial relation between fiber quality and soil variability and possibly in the future to direct variable application systems.

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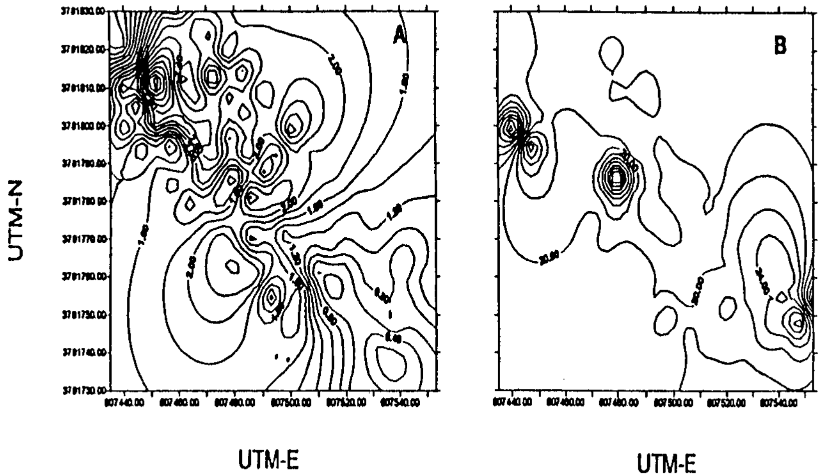

Fig. 1. Kriged maps for (a) cotton fiber yield and (b) soil moisture from 1996 South Carolina experiment.

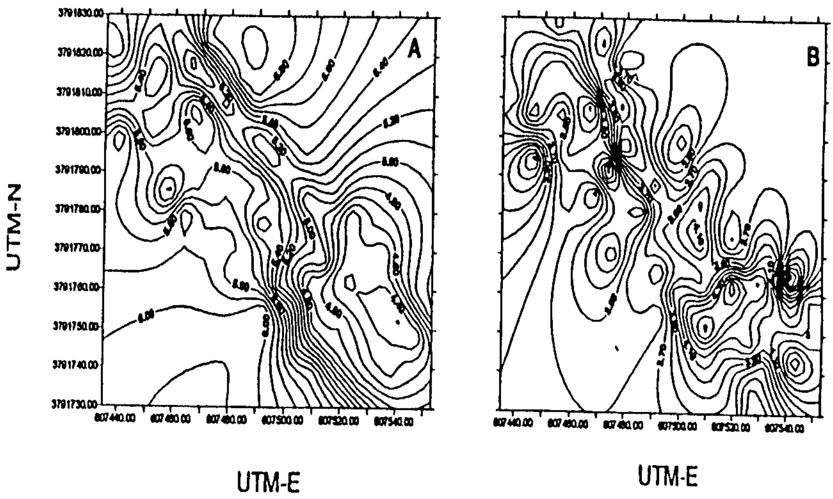

Fig. 2. Kriged maps for (a) soil pH and (b) fiber micronafis from 1996 South Carolina experiment.