SITE-SPECIFIC MANAGEMENT OF COTTON FIBER QUALITY

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ABSTRACT

The market value of every bale of cotton fiber grown in the United States is partially determined by price penalties assessed according to USDA classing office measurements of bale-average fiber quality. Although genotype is the major factor in some fiber properties, variations in environmental factors are the chief determinants of micronaire (maturity + fineness), color, and shape uniformity. Fruiting-site-specific maps of cotton plants have been used to describe the spatial variability of fiber quality within plants and among environmental treatments. Integration of such within-plant maps with field maps of spatial variability in soil properties, yield, and fiber properties would allow site-specific optimization of cultural-inputs and other production practices (*e.g.*, application of fertilizer, water, or plant growth regulators). Correlations among spatial variations in fiber properties, soil pH, levels of phosphorus, sodium, calcium, magnesium, cation exchange capacity, or organic matter were examined in a two-year study of Upland cotton grown in South Carolina. In both years, higher levels of phosphorus and organic matter were associated with increased fiber maturity and micronaire. Increased levels of phosphorus were also linked to decreased fiber yellowness and increased fiber whiteness, color shifts that connote higher fiber quality. Higher levels of potassium and percent organic matter were also correlated with improved fiber whiteness. The presence of poorly drained Carolina Bay landforms correlated with elevated levels of percent organic matter and soil phosphorus, soil parameters that were negatively correlated with yield in both years. The field sites highest in pH or calcium and magnesium content produced immature fiber with micronaire in the price-penalty range below 3.5, an effect that intensified in the drier year of the study. These preliminary results suggest several site-specific strategies for pre-harvest improvement of cotton fiber.

INTRODUCTION

Cotton plant mapping by fruiting site at the boll or field-block level has revealed extensive modulation of fiber properties by the growth environment (Bradow *et al.*, 1997a; 1997b; 1997c). Those cotton fiber properties related to maturity, *i.e.*, fiber cell-wall thickness (θ), micronaire (empirical measure of fiber fineness *and* maturity), and fiber cross-sectional area, were particularly sensitive to the thermal environment as described by cumulative Growth Degree-Days (GDD) with a base temperature of 13.5°C and ceiling temperature of 32°C (Bradow *et al.*, 1997b; Johnson *et al.*, 1997). When day-length and insolation were added to the GDD model, the coefficients of determination describing the variability in the fiber maturity properties, immature fiber fraction, fiber cross-sectional area, and micronaire, were 80%, 71% and 82%, respectively.

The studies upon which the GDD models were based did not include soil properties or fiber color, an important factor in the price and end-use of the cotton crop (Deussen and Faerber, 1995; Larson and Meyer, 1996). Therefore, a two-year experimental design incorporating site-specific mapping of soil spatial variability was begun in 1996 in a commercial field in Florence, South Carolina, USA. This report considers the correlations and spatial distributions found among the maturity-related fiber properties (θ, immature fiber fraction, cross-sectional area, micronaire or the analogous micronAFIS, and color, *i.e.*, whiteness and yellowness) and edaphic variables (water content, organic matter content, pH, cation exchange capacity, and soil levels of phosphorus, sodium, potassium, calcium, and magnesium).

MATERIALS AND METHODS

A field experiment investigating the influence of soil spatial variability on variations in fiber yield and quality of cotton (*Gossypium hirsutum*, genotype LA 887) was conducted in a producer's field in Florence, South Carolina, in 1996 and 1997 (Bradow, *et al.*, 1998; Johnson *et al.*, 1998). Soil samples (0-20 cm) were collected shortly after planting in May of each year from the same rectangular grid (120 x 40-m rectangle with 7.5-m grid intervals). The grid location was chosen to include a Carolina Bay landform in order to assure a significant and representative range in soil variability. Soil properties determined included percent soil moisture, percent organic matter, pH, Ca, Mg, K, P, Na (all ions, mg kg^{-1} soil), and cation exchange capacity (CEC, meq 100 g^{-1} soil).

In October of both years, cotton fiber samples were hand-collected from approximately one meter of row centered on the grid points. Fiber was saw-ginned and weighed to determine fiber yield in 218-kg bales. The bulk fiber samples were then sub-sampled for measurements of fiber properties. Two methods of fiber-quality quantification were employed. The Zellweger Advanced Fiber Information System (AFIS-A2) was used for all samples (Bradow *et al.*, 1997a), and the High Volume Instrument (HVI) method was used when the fiber sample weight from a grid point was ≥ 50 g (Moore, 1996). Fiber properties determined by AFIS and included in this report were: degree of wall thickening (θ), immature fiber fraction (IFF, % distribution of $\theta < 0.25$), cross-sectional area by number (An), and micronAFIS (calculated micronaire analog dependent on θ and An measurements). Properties determined by the HVI method and reported here were micronaire, fiber bundle elongation percent and color estimated by the degree of reflectance (Rd, whiteness) and yellowness (+b).

Both conventional univariate statistics (SAS PROC UNIVARIATE) and variogram analysis (GeoEas) were used in the analyses of all fiber and soil data. Prior to variogram analysis, the spatial data were de-trended by fitting a plane surface through each data set (SAS PROC REG), evaluating the surface of each data point, and subtracting the surface from the raw data (Sadler *et al.*, 1998). Simple correlation analyses were 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), utilizing the previously determined variograms.

RESULTS AND DISCUSSION

Variability of soil properties

Soil properties from the 1996 and 1997 growing seasons are presented in Table 1. In both years of the study, all soil properties (with the exception of sodium in 1996) were non-normally distributed as determined from the Shapiro-Wilkins statistics (Johnson *et al.*, 1998). These soil properties exhibited a positive skew with the mean greater than

TABLE 1. Univariate statistics for soil properties from a Florence, South Carolina, grower's field in 1996 and 1997. All ion concentration means are in mg kg^{-1}; cation exchange capacity, CEC, means are meq 100 g^{-1} soil.

Soil property	*n*	Mean	Median	Standard Deviation	Coeff. of Variation	Skew
Soil water %						
1996	102	19.7	18.9	3.9	19.7	2.1
1997	102	9.1	8.5	1.9	21.0	1.1
Phosphorus						
1996	102	158.8	111.4	116.8	73.6	1.0
1997	102	161.8	109.5	119.3	73.7	1.1
Sodium						
1996	102	5.9	5.9	1.9	31.7	0.04
1997	102	6.3	6.1	1.9	30.6	0.82
Potassium						
1996	102	142.9	139.4	45.2	31.7	0.30
1997	102	145.4	140.6	45.0	31.0	0.37
Calcium						
1996	102	217.3	205.4	73.3	33.7	0.61
1997	102	251.4	242.9	78.8	31.3	1.1
Magnesium						
1996	102	49.5	46.3	16.1	32.5	0.86
1997	102	56.3	50.6	18.2	32.4	0.52
Soil pH						
1996	102	5.2	5.3	0.48	9.1	-0.33
1997	102	5.0	5.1	0.53	10.6	-0.22
Organic matter						
1996	102	0.86	0.6	0.54	62.8	1.2
1997	102	0.82	0.5	0.50	61.1	1.3
CEC						
1996	102	1.6	1.5	0.57	35.8	0.38
1997	102	2.1	2.0	0.60	28.4	0.55

the median (with the exception of pH in both years). Soil pH exhibited a slight, but measurable, negative skew in both 1996 and 1997. With the exception of soil water percent, the 1996 and 1997 soil-property means differed by less than one standard deviation, and comparison of the meteorological data from the two years indicate that 1997 was indeed a drier year than 1996. The average yield was also about 18% lower in 1997 (Table 2). The coefficients of variation for data from both years were also similar (Table 1), and the range of variability in soil properties was sufficiently large to suggest that site-specific management strategies could be beneficial.

TABLE 2. Univariate statistics of LA 887 cotton-fiber properties in 1996 and 1997.

Fiber property	n	Mean	Median	Stand. Deviation	Coeff. of Variation	Skew
θ (degree of wall thickening or circularity where θ = 1.0 for a perfect circle)						
1996	100	0.470	0.500	0.040	9.3	-1.11
1997	101	0.480	0.500	0.050	10.4	-0.39
IFF (Immature Fiber Fraction, % fiber with θ < 0.25)						
1996	100	14.5%	14.5%	2.1%	14.8	0.36
1997	101	12.8%	12.9%	2.6%	20.2	0.10
Area (An, cross-sectional area)						
1996	100	106.8 μ^2	107.0 μ^2	6.7 μ^2	6.3	-0.11
1997	101	100.6 μ^2	110.0 μ^2	7.8 μ^2	7.0	+0.39
MicronAFIS (calculated from An and θ)						
1996	100	3.8	3.8	0.39	10.3	-0.01
1997	101	4.1	4.0	0.54	13.2	+0.37
Micronaire (empirical measure of fiber fineness and maturity)						
1996	85	3.8	3.8	0.35	9.2	-0.10
1997	79	4.0	3.9	0.40	10.1	+0.25
Elongation %						
1996	85	6.3%	6.3%	0.25%	4.0	-0.45
1997	79	6.6%	6.6%	0.35%	5.3	-1.13
Rd (white)						
1996	85	76.9	76.9	1.73	2.3	-0.14
1997	79	76.5	76.5	1.61	2.1	-0.36
+b (yellow)						
1996	85	8.8	8.8	0.61	6.9	0.43
1997	79	9.6	9.6	0.59	6.1	0.22
Yield (218-kg bales)						
1996	102	1.58	1.55	0.83	52.3	0.33
1997	79	1.30	1.40	0.57	43.0	0.29

The soil properties variogram analysis from the two years showed all soil properties to be spatially correlated, with the exception of soil pH (Johnson, *et al.*, 1998). The semivariogram for soil moisture was linear in 1996 and spherical in 1997. The semivariograms for soil organic matter and CEC were similar in range from 1996 to 1997, but the best-fit model in 1997 was Gaussian, rather than spherical, as in 1996.

Variability in fiber properties

Fiber maturity and yield data from 1996 and 1997 are presented in Table 2. The number of replicate samples (n) is lower for the data obtained with HVI (micronaire, elongation percent, and the color components, Rd and +b) because reproducible HVI fiber measurements require individual fiber samples of at least 50 grams. In the two growing seasons, some grids did not produce sufficient fiber for HVI analyses.

In both years, the data for the majority of the fiber properties examined were normally distributed. The exceptions were θ (*i.e.*, cell-wall thickness), and fiber-bundle elongation percent. Data for these fiber properties were negatively skewed in 1996. In 1997, θ and elongation percent showed slight negative skews. The negative skewing of the θ data indicates an increased population of immature fiber contributing to the means, which did not differ significantly in the two years of the study. This effect is also seen in comparisons of the immature fiber fraction (IFF) data from the two years. The higher proportion of immature fiber in the 1996 crop was also associated with increased fiber whiteness, or Rd, and decreased +b yellowness. Fiber maturity, quantified as θ, was negatively correlated with yield in both years.

The coefficients of variation ranged from *ca.* 2.0 % in the Rd (whiteness) data to over 40% in the yield data in both years. The range of coefficients of determination for micronaire and micronAFIS variability was from 9.2 to 13.2%, and a decrease of one standard deviation from the mean would place the 1996 micronaire and micronAFIS levels in the low-micronaire price-penalty range of less than 3.5. All these fiber maturity and yield properties are strongly influenced by environmental variations and should benefit from improved site-specific management strategies.

Cotton yield was spatially correlated with exponential semivariograms in both 1996 and 1997 (Johnson *et al.*, 1998). The range of spatial correlation decreased slightly from 30 m in 1996 to 27 m in 1997. The majority of the fiber properties were also spatially correlated. The exceptions relevant to this report were Rd and +b in 1996 and θ in 1997. The exponential model fit the majority of the fiber properties in 1996 and 1997, the exception being IFF, which was described by the spherical model in 1996 only. In 1997, the exponential model described all properties, except +b (yellowness), which was Gaussian. The range of spatial correlation was similar in both years with most properties correlated between 15 and 30 m. In 1997, +b had a range of 43 m.

Correlation analyses of soil and fiber variability

Results from the correlation analyses between soil and fiber properties from the combined two-year data set are found in Table 3. When the fiber properties that determine cotton prices, *i.e.*, micronaire and the color factors, Rd and +b, are considered, several site-specific strategies for improving production management are suggested by these simple correlation analyses. For example, increased soil water percent would have had no effect on HVI micronaire but would have improved fiber whiteness (Rd). The negative correlation between micronAFIS (the more complete data set) and soil water percent and the corresponding positive correlation with IFF suggest that increased water availability might have decreased fiber maturity and micronaire, thus reducing the quality and value of the crop. Raising soil pH would also have had an undesirable effect on micronaire and Rd, and an increase in soil organic matter would have increased micronaire and Rd. Addition of phosphorus would have increased fiber maturity, micronaire, and Rd and reduced fiber-bundle elongation percent, a change associated with increased fiber maturity. Application of lime would not be advisable due to the negative correlations between calcium and magnesium and θ, micronAFIS and cross-sectional area, as well as the positive correlation between those cations and fiber yellowness, an undesirable color property since whiter, less yellow fiber brings the higher price.

Table 3. Simple (Pearson's) correlation coefficients between soil and fiber properties for combined (1996 and 1997) data set. OM = organic matter, CEC = cation exchange capacity.

Fiber Property	Soil water %	P	Ca	Mg	pH	OM	CEC
θ	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
Micron AFIS	-0.17*	0.40***	-0.20**	-0.20**	-0.51***	0.32***	ns
Micro-naire	ns	0.22**	ns	ns	-0.26***	0.17*	ns
Elong'n %	-0.44**	-0.21**	ns	0.16*	ns	-.017*	0.28***
Rd	0.21**	0.37***	ns	ns	-0.26***	0.42***	ns
+b	ns	ns	0.19*	0.19*	ns	ns	0.21***

The symbols, ns, *, **, *** indicate non-significant and significance at the 0.05, 0.01, and 0.001 probability levels, respectively.

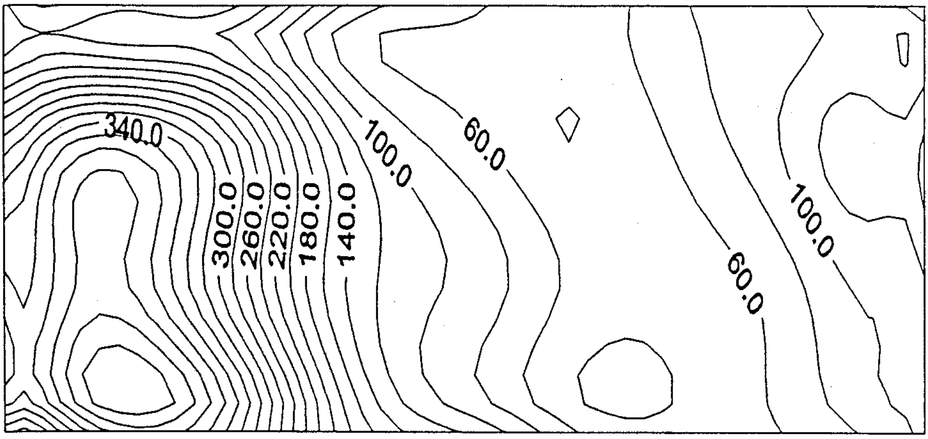
Soil and fiber maps.

The simple correlations shown in Table 3 cannot demonstrate cause and effect relationships among soil and fiber spatial variability, but the correlations do serve as useful guides for comparisons among the variograms and site-specific maps derived from these data. The relationship between the spatial variabilities in soil phosphorus and micronAFIS is apparent in Figures 1 and 2 where the higher phosphorus levels are associated with increased micronAFIS. The negative relationship between spatial variabilities in micronAFIS and in soil pH can also be seen in Figure 1 and 2 where higher micronAFIS values are associated with lower pH. The zonal relationships between micronAFIS and whiteness (Rd) can be seen in Figures 2 and 3.

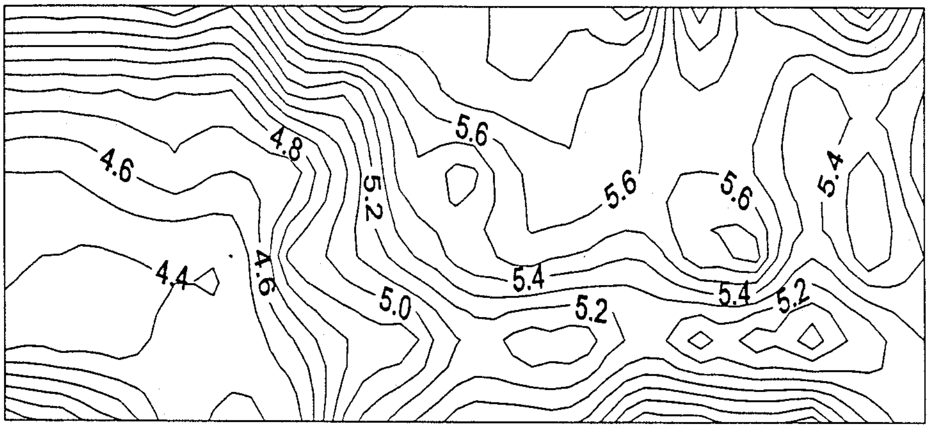
CONCLUSIONS

The three soil properties mapped in Figure 1 could be modified on a site-specific basis. Further, zone-management practices modified in accordance with these maps would allow the producer to improve the fiber qualities of the cotton crop *before harvest* and the assessment of post-classing fiber-quality price-penalties. The power of these spatial-variability maps for site-specific prediction of fiber properties can also provide guidance for selective harvesting of field sites producing the higher-grade, more valuable fiber. This South Carolina experiment is being repeated in Louisiana, and those replications in space and time are expected to increase the predictive power and usefulness of site-specific soil and fiber maps.

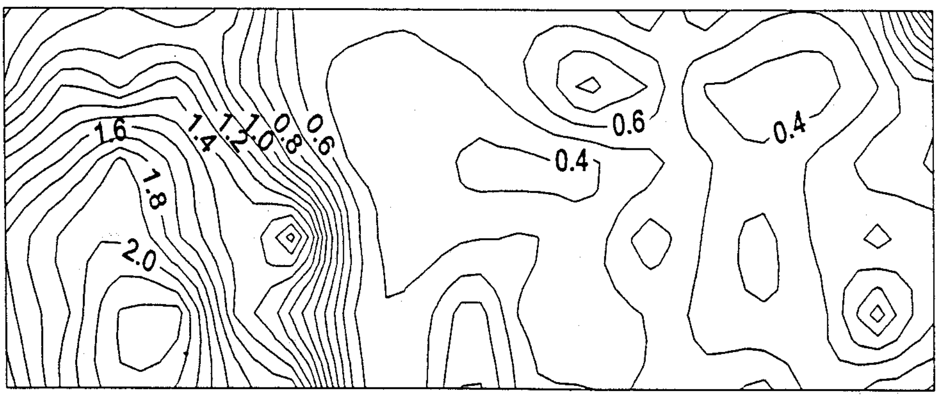
Figure 1. Soil Properties from South Carolina Field Experiment (1996)



Soil Phosphorus

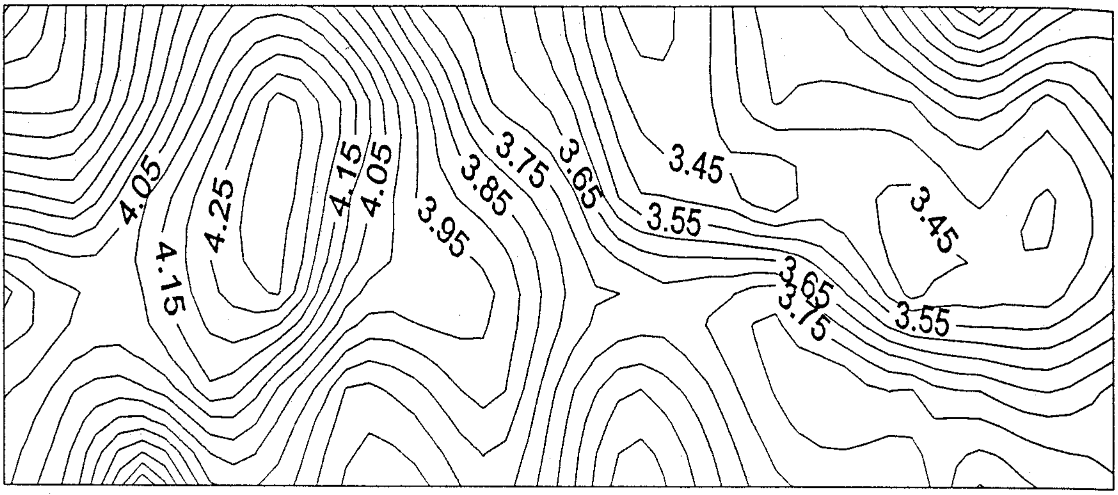


Soil pH

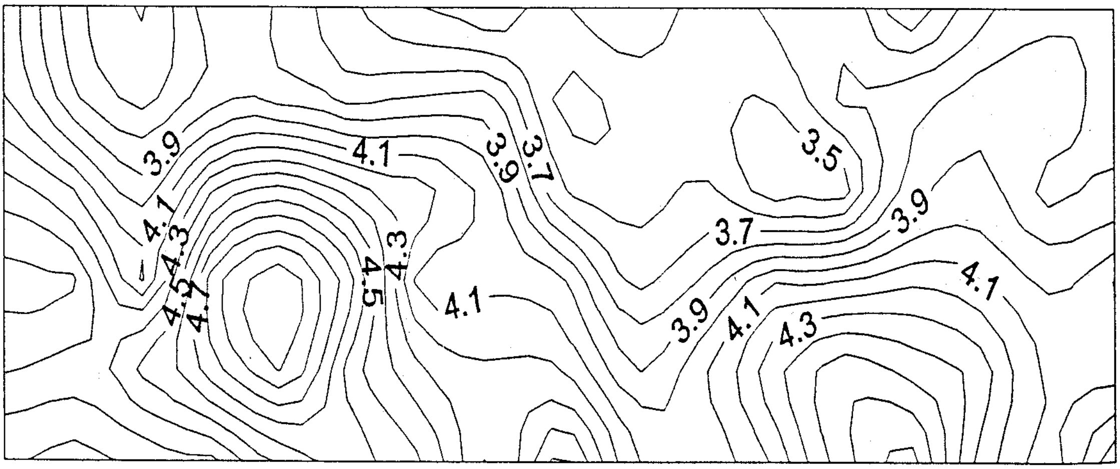


Soil Organic Matter

Figure 2. Cotton Fiber MicronAFIS Values from South Carolina Field Experiment.

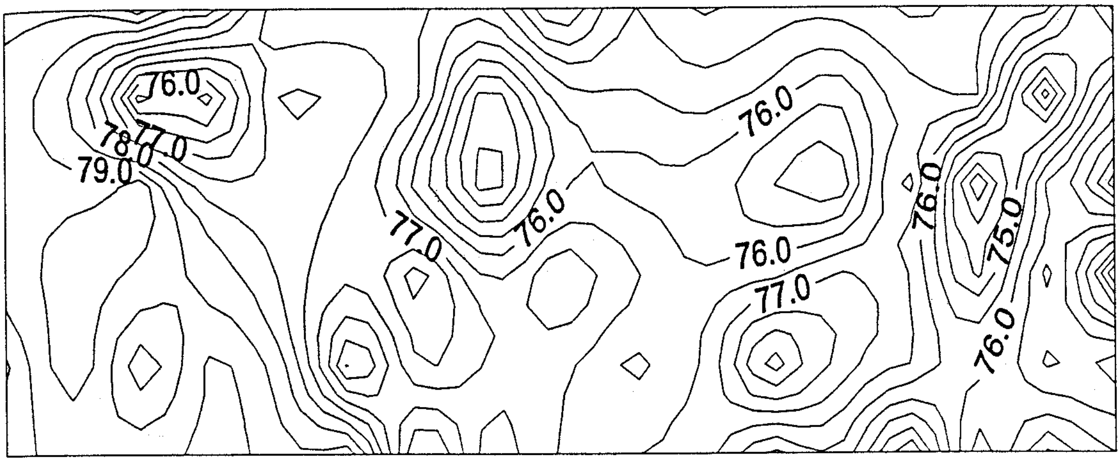


1996

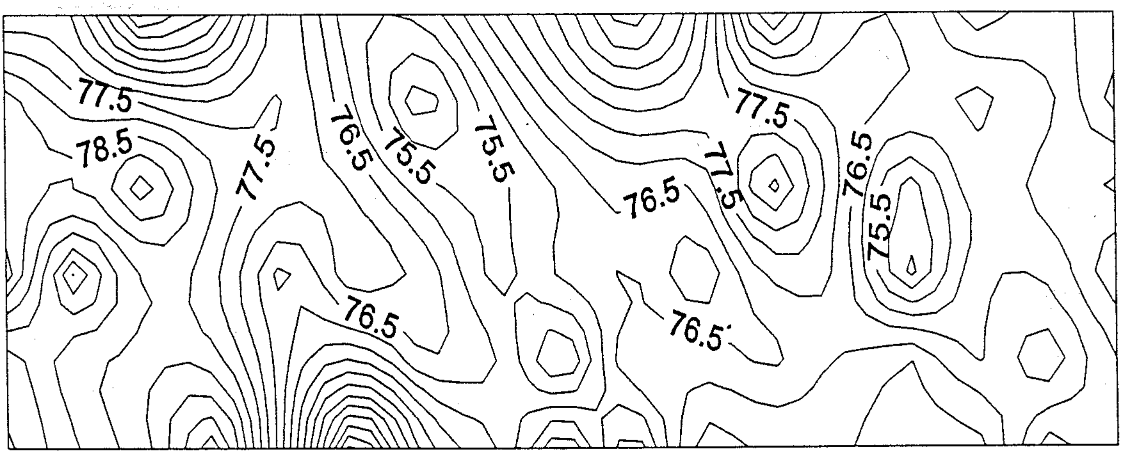


1997

Figure 3. Cotton Fiber Reflectance (Rd) from South Carolina Field Experiment



1996



1997

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