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Spatial variation of fiber quality and associated loan rate in a dryland cotton field

Yufeng Ge · J. Alex Thomasson · Ruixiu Sui · Cristine L. Morgan · Stephen W. Searcy · Calvin B. Parnell

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Abstract A field study was conducted in 2006 in a dryland cotton field in Texas, USA, to explore the spatial variation of cotton fiber quality and the loan rate associated with it. A total of 66 cotton samples were hand-harvested, and the fiber quality properties investigated included the High Volume Instrument measurements of micronaire, length, uniformity, strength, elongation, reflectance (Rd) and yellowness (+b). Conventional statistics showed a generally low level of variation in fiber quality with coefficients of variation <10%. Variogram analysis showed that all fiber quality properties were spatially correlated. Contour maps of individual fiber quality properties were produced from block kriged estimates. Fiber length, uniformity, strength and Rd were positively correlated, and all of these were negatively correlated with +b. The spatial distribution of most fiber quality properties was similar to that of soil apparent electrical conductivity, suggesting that water holding capacity could be a limiting factor for cotton fiber quality. Maps of individual fiber quality properties were combined with the United State Department of Agriculture—Commodity Credit Corporation Loan Schedule for Upland Cotton to create a loan rate map that is associated with fiber

Y. Ge (✉) · C. L. Morgan
Department of Soil and Crop Sciences, Texas A&M University, Heep Center, 370 Olsen Boulevard, College Station, TX 77843, USA
e-mail: yg36@tamu.edu

C. L. Morgan
e-mail: cmorgan@ag.tamu.edu

J. A. Thomasson · R. Sui · S. W. Searcy · C. B. Parnell
Department of Biological and Agricultural Engineering, Texas A&M University, College Station, TX 77843, USA
e-mail: thomasson@tamu.edu

R. Sui
e-mail: rsui@tamu.edu

S. W. Searcy
e-mail: s-searcy@tamu.edu

C. B. Parnell
e-mail: c-parnell@tamu.edu

quality. A loan rate difference of 20 cents kg^{-1} was observed within the field. This level of difference indicated that fiber quality at the field level can have a large impact on producers' revenue. A site-specific management system encompassing both lint yields and fiber quality is strongly recommended for cotton production.

Keywords Block kriging · Cotton · Fiber quality · Geostatistics · Loan rate · Site-specific crop management · Spatial variability

Introduction

Site-specific crop management (SSCM) in cotton production has developed significantly over the last few years. Several studies have been undertaken on the development of cotton yield monitors (Wilkerson et al. 2001; Thomasson and Sui 2003; Vellidis et al. 2003), remote sensing (Plant et al. 2000; Yang et al. 2005), real-time plant-condition sensors (Searcy and Beck 2000; Sui and Thomasson 2006), variable-rate technologies (Fridgen et al. 2004; Perry et al. 2004), and cotton yield modeling (McKinion et al. 2001). While most of the research considers yield as a predominant profit factor in applying SSCM, technological advances to take account of cotton fiber quality have lagged far behind. In reality, however, fiber quality is important in determining profit for cotton producers. In the USA, virtually every bale (around 228 kg of lint) of cotton produced is subject to the High Volume Instrument (HVI) fiber quality measurement regulated by the United States Department of Agriculture-Agricultural Marketing Service (USDA-AMS). Based on this measurement, bales with high quality fibers are rewarded with premium rates, whereas low quality bales are penalized with discounts (USDA 2001). In recent years, the issue of fiber quality has aroused more attention, partly because of pressure from manmade synthetic fibers and technological progress in textile processing. A reflection of this is that USDA-AMS has continued to try to integrate additional fiber quality properties (such as short fiber content and stickiness) into the HVI testing, and has proposed the inclusion of these properties into the commercial system for cotton pricing and marketing. It is important, therefore, to envisage an SSCM system that could encompass both lint yields and fiber quality such that a producer's field management could be optimized with respect to profit.

To date, the within-field variation of fiber quality has been determined mainly by taking cotton samples manually from various locations in a field and summarizing the data in terms of descriptive statistics, such as the range and coefficient of variation (CV). Table 1 gives the mean and CV of lint yields and HVI fiber quality properties from several studies in the literature. More recently, geostatistical methods have been used in conjunction with conventional statistics to analyze fiber quality data. For example, Wang (2004) calculated the Moran's I statistic to detect the spatial correlation existing in micronaire. Johnson et al. (2002) used variogram analysis to show that many HVI and Advanced Fiber Information System (AFIS) fiber quality properties were spatially dependent.

Cotton fiber quality properties are suited to geostatistical analysis because they are likely to be spatially correlated as are many crop and soil properties (Solie et al. 1999; Ge et al. 2007). Geostatistics takes spatial dependence into account and provides a more appropriate framework for spatial data analysis than conventional statistics. It also provides a statistically optimal method of estimation (kriging) to predict fiber quality properties at unsampled locations. For SSCM to be practiced in cotton production, it is important to consider the likelihood that fiber quality depends on agronomic and environmental

Table 1 Summary of mean and CV (coefficient of variation) of lint yields and High Volume Instrument fiber quality properties in the literature

Source	Year	Statistics	Fiber quality properties							
			Yield (kg ha^{-1})	Micronaire	Length (mm)	Uniformity (%)	Strength (g tex^{-1})	Elongation (%)	Rd	+b
Elms et al. (2001)	1996	Mean	989	5.1	27		31.1			
		CV (%)	21.2	10.4	4.2		15.4			
	1997	Mean	845.0	4.8	27		32.2			
		CV (%)	20.4	4.5	2.3		3.9			
	1998	Mean	992.0	4.6	27		29.5			
		CV (%)	23.2	5.8	3.0		2.2			
Johnson et al. (2002)[a]	1996	Mean	851.8	3.8	28.3	82.1	28.5	6.3	79.6	8.83
		CV (%)	52.3	9.2	2.8	1.7	4.8	4.0	2.3	6.9
	1997	Mean	714.6	3.95	28.5	83.3	29.6	6.6	76.5	9.6
		CV (%)	43.0	10.1	3.3	1.4	5.2	5.3	2.1	6.1
Ping et al. (2004)	1998	Mean	956.4	4.4	27.9		30.2			
		CV (%)	18.9	10.6	3.2		5.7			
	1999	Mean	891.4	4.6	27.1		28.9			
		CV (%)	18.3	6.6	2.3		4.6			
	2000	Mean	661.7	3.3	26.8		29.2			
		CV (%)	24.0	10.9	2.8		5.9			
Wang (2004)[b]	1999, 2000	Mean		4.19	33.56	81.43	26.8		71.28	7.35
		CV (%)		11.06	2.78	1.44	6.8		4.25	7.78

[a] In this article, strength was originally reported in kN m kg^{-1}

[b] In this article, the 2-year data were pooled for summary

conditions in a different way from lint yields (Sassenrath et al. 2005). Thus, maps of fiber quality and lint yields are likely to show different spatial patterns. Subsequent delineation of management zones and agronomic decisions would be different depending on whether one focuses on yield or fiber quality. There is a need to consider both simultaneously, but no adequate method is currently available to measure the spatial variation of fiber quality exhaustively and automatically (Sassenrath et al. 2005). Hence geostatistics is advantageous as it can produce high resolution maps of estimates from coarsely spaced sample data. Such maps would enable straightforward visualization of the variation in fiber quality over the field. When compared to maps of other spatial data, such as soil, relationships between fiber quality and the growing environment might be identified.

The research objectives of this study were to quantify the spatial variation of: (1) fiber quality and (2) loan rate associated with fiber quality in a dryland cotton field in Texas, USA. We hope that this study will raise awareness among farmers that fiber quality has a significant impact on their revenues at the field level and that there are opportunities to improve production practices relative to fiber quality.

Materials and methods

Study site

The field study was conducted in 2006 in a dryland cotton field located on the Texas A&M University Research Farm in Burleson County, about 16 km southwest of College Station, Texas (latitude 30.5298°N, longitude 96.4363°W). The field is about 12 ha in size and was in a sorghum–sorghum–cotton–cotton rotation 4 years before the experiment. The dominant soil types indicated by the USDA-NRCS (Natural Resource Conservation Service) soil survey include a Roetex clay (very fine, mixed, active, thermic Aquic Hapluderts), a Weswood silty loam (fine-silty, mixed, superactive, thermic Udifluventic Haplustepts) and a Weswood silty clay loam (fine-silty, mixed, superactive, thermic Udifluventic Haplustepts). Cotton variety “DPL 455 BG/RR” (Delta and Pine Land Company, Scott, Mississippi, USA) was planted on 4th April 2006 with a seeding rate of 128 000 seeds ha^{-1} and a row spacing of 0.76 m. Other field management practices including the application of fertilizers, pesticides, growth regulators and defoliants followed the recommendations made by the Texas Cooperative Extension, Texas A&M University, Texas, USA.

Sampling design and data collection

To assess the spatial variation of cotton fiber quality, a total of 66 sampling points was laid out in the field. Thirty-six of the points belong to a regular grid with an average spatial interval of 55 m from a previous year’s field study (Fig. 1). In 2006, ten closely spaced off-grid transects (each transect comprised three sampling points with separation distances of 20, 10 and 5 m) were added in four directions (0°, 45°, 90° and 135° to the row direction) into the grid (Fig. 1) to enable more accurate estimation of the variograms of cotton fiber quality. The position of each sampling point was established by using a GPS receiver (iFINDER™, Lowrance Electronics, Inc., Tulsa, Oklahoma, USA) with Wide Area Augmentation System (WAAS) correction.

Before machine harvest, cotton samples were hand-harvested about 3 days after defoliants were applied (5th August 2006). Around 0.45 kg (~1.0 lb) of seed cotton was harvested from each sampling point and placed in a numbered paper bag. There were

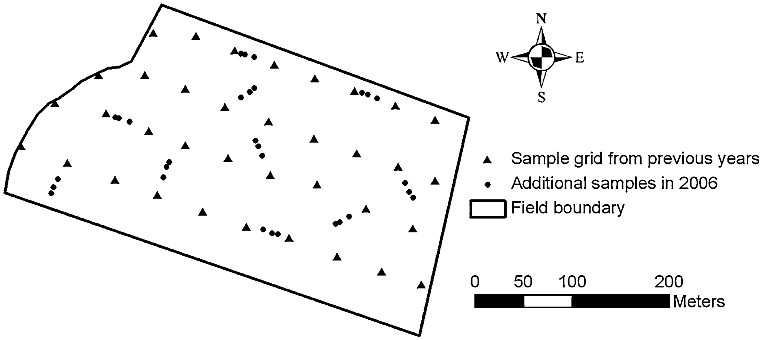

Fig. 1 Boundary of study field and locations of sampling points

concerns about the large variation in cotton fiber quality among bolls from different plants and fruiting sites (Bradow et al. 1997). To keep samples from being biased toward an individual cotton plant or a specific fruiting site, seed cotton was harvested from at least 10 plants from two neighboring rows at each location; and bolls from the top, middle and bottom parts of the plant were picked evenly. Seed cotton from small, immature, and partially opened bolls was not harvested.

Cotton samples were ginned at the Cotton Improvement Laboratory, Texas A&M University. The facility was a 10-saw laboratory-scale gin with no seed cotton or lint cleaning (Continental Eagle Corporation, Prattville, Alabama, USA). The ginned lint samples were sent to the International Textile Center, Texas Tech University (Lubbock, Texas, USA) and subjected to HVI testing, which includes micronaire, length, length uniformity, strength, elongation, reflectance (Rd), yellowness (+b), and color and leaf grades.

Statistical analysis

Exploratory data analysis was performed to describe the variation of fiber quality properties in terms of conventional statistics. Color and leaf grades are categorical variables and were not included in either exploratory or geostatistical analyses. Moreover, these properties are more likely to be affected by non-agronomic factors, such as harvesting, storage and ginning methods, than other properties and they were considered of less importance in this work. The univariate statistics reported for the remaining fiber quality properties include the maximum value (Max), minimum value (Min), mean, standard deviation (SD) and CV. The exploratory data analysis was performed with the SAS Procedure, UNIVARIATE (SAS Institute, Cary, North Carolina, USA).

Variogram analysis was applied to quantify the spatial structure of the fiber quality properties. There was no evidence of trend in an initial posting of the data. It was assumed that the spatial structure was isotropic because the number of cotton samples (66) was insufficient to determine any anisotropy in the variation. The experimental variogram was computed by Matheron's (Matheron 1965) method of moments (MoM) estimator. The equation is given by

$$\hat{\gamma}(\mathbf{h}) = \frac{1}{2N(\mathbf{h})} \sum_{i=1}^{N(\mathbf{h})} [z(\mathbf{s}_i) - z(\mathbf{s}_i + \mathbf{h})]^2 \tag{1}$$

where $N(\mathbf{h})$ is the number of sample pairs separated by the lag distance $\mathbf{h}$; and $z(\mathbf{s}_i)$ and $z(\mathbf{s}_i + \mathbf{h})$ stand for the fiber quality property measured at sample locations $\mathbf{s}_i$ and $(\mathbf{s}_i + \mathbf{h})$, respectively.

The experimental variograms were fitted (based on a weighted least squares approximation) with theoretical models that provide three parameters: c_0, the nugget variance, $c_0 + c_1$, the sill variance, and a, the range of spatial dependence. These model parameters describe the spatial structure of fiber quality properties. The spherical model (Eq. 2, Journel and Huijbregts 1978) generally fitted the experimental variograms better than other models. Its equation is given by

$$\gamma(h) = \begin{cases} c_0 + c_1\left[\frac{3}{2}\frac{h}{a} - \frac{1}{2}\left(\frac{h}{a}\right)^3\right] & \text{for} \quad h \le a \\ c_0 + c & \text{for} \quad h > a \end{cases} \tag{2}$$

Some researchers (Webster and Oliver 1992; Kerry and Oliver 2007) have pointed out that a sample size of about 100 is required for reliable estimation of the variogram by MoM. For small sample sizes of 50 or more, variograms should also be estimated by the maximum likelihood (ML) approach and compared to those estimated by MoM (Lark 2000; Kerry and Oliver 2007). As a result of the small sample size in this study, we also estimated the variograms by residual maximum likelihood (REML, Patterson and Thompson 1971). The quality of variograms estimated by MoM and modelled by weighted least squares fitting was then compared with those computed by REML. The model parameters from the MoM variograms were used for subsequent kriging.

The parameters of the fitted models were used with the associated data for block kriging of selected fiber quality properties. Block kriging estimates the average value of the target variable over an area (or a block) rather than at a point. The block size used was 2 × 2 m. The block kriged estimates were then used for mapping. Maps generated by block kriging have fewer local extremes because the local detail is smoothed (Isaaks and Srivastava 1989). This smoothing feature of block kriging was desirable in this study because cotton price is based on its bulk fiber quality, and it is more useful to show the general pattern of variation in fiber quality than extreme values at certain locations. The variogram analyses (experimental variogram computing, model fitting and REML) were performed with the geoR package in R software, and block kriging and mapping were implemented in Surfer 7 (Golden Software, Golden, Colorado, USA).

Results and discussion

Exploratory statistics

Exploratory statistics for fiber quality properties are given in Table 2. The CV ranged from 1.6% for uniformity and Rd to 9.5% for micronaire. Micronaire has the highest CV, which is

Table 2 Exploratory statistics of fiber quality properties in the study field (n = 66)

Fiber quality properties	Max	Min	Mean	SD	CV (%)
Micronaire	4.87	3.05	3.62	0.34	9.48
Length (mm)	31.5	25.4	28.2	1.54	5.47
Uniformity (%)	84.5	77.3	81.5	1.30	1.59
Strength (g tex^{-1})	31.6	25.8	28.1	1.34	4.75
Elongation (%)	6.10	4.20	5.35	0.35	6.54
Rd	81.7	75.2	78.2	1.24	1.59
+b	10.9	8.70	9.84	0.50	5.08

in agreement with other studies in the literature (Table 1) that show micronaire had a larger CV than other HVI fiber properties. Micronaire reflects fiber maturity for a given variety of cotton, therefore the observed greater variation in it agrees with the idea that fiber maturity is influenced more by the growth environment than other properties such as length and strength (Johnson et al. 2002). Overall, the variation in fiber quality in this study is generally small with a CV $<$ 10% for all properties (Table 2), which supports the results of other studies where CVs for fiber quality were much less than those of lint yields (Table 1). This is not surprising because fiber quality is, to a large extent, associated with genetic traits and we should expect it to show less response to the environment than does yield. It is also a reason why farmers have made less effort to deal with fiber quality than lint yields in the field. However, if large differences in loan rates were caused by the variation of fiber quality, a farmer could increase his revenue substantially by addressing this issue properly.

Geostatistics

The experimental variograms of individual fiber quality properties and the fitted spherical models are shown in Fig. 2, together with the spherical models estimated by REML. The variogram model parameters are given in Table 3. The parameters of the variogram models estimated by the two methods are generally similar, suggesting that, in spite of the small sample size, the MoM variogram parameters are sufficiently reliable for further analysis. All fiber quality properties show an appreciable level of spatial dependence, with the percentage nugget variance (nugget/sill $\times$ 100%) varying from 5.3% for +b to 60% for Rd. The degree of spatial structure shown by the variograms indicates that geostatistics is an appropriate tool for quantifying within-field variation of cotton fiber quality. The ranges of spatial dependence for all fiber quality properties are comparable; they vary from 101 m for uniformity to 163 m for length.

It is interesting to note that all fiber quality properties have a noticeable nugget component. The nugget variance usually comprises two main components: (1) variation over distances much less than the sampling interval, and (2) measurement error (Isaaks and Srivastava 1989). Bradow et al. (1997) showed that there are large variations in fiber quality at the plant, boll and even lock (sub-section of a cotton boll) level. Each cotton sample in this study was taken from a large number of bolls on more than 10 individual plants. Therefore, the between-boll variation should have been integrated into the sample variance and so reduce the effect of this local variation on the nugget. Furthermore, the USDA (2001) has specified the repeatability of HVI measurement for individual fiber properties (e.g., micronaire has $\pm$0.150 unit measurement repeatability). This repeatability should be reflected as the measurement error component of the nugget. We can assume that most of the nugget variance derives from variation between the sampling sites.

Fiber quality maps

Figure 3 shows the contour maps of selected fiber-quality properties in the study field. Maps for elongation are not included because it is not in the current USDA-AMS cotton pricing system and thus would not contribute to the loan rate map. Length, uniformity, strength and Rd have similar spatial patterns, with large values in the north central portion of the field and small values in the southwestern and mid-eastern portions (Fig. 3). The pattern for +b is the reverse of these, with small values in the north central and large values in the southwestern and mid-eastern portions. Micronaire has a different spatial pattern, with small values mainly in the eastern area and large values in the northwestern corner of the field.

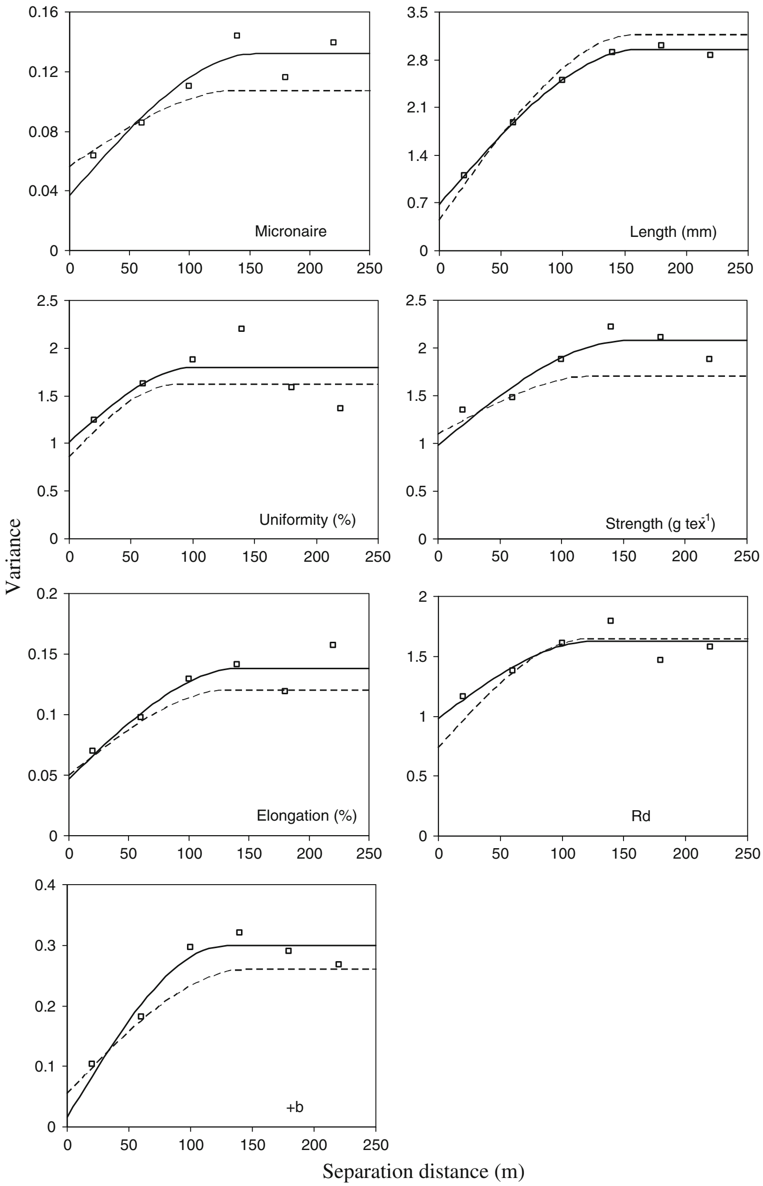

Fig. 2 Variograms of fiber quality properties in the study field: experimental variograms (□) calculated by method of moments estimator, spherical models fitted by weighted least squares (—), and spherical models estimated by residual maximum likelihood (- - -)

The similar spatial patterns shown in length, uniformity and strength suggest that these fiber quality properties are positively correlated and this is confirmed by the correlation coefficients (Table 4). The spatial patterns might also indicate that these fiber quality properties have a similar response to certain agronomic or environmental factors. Table 4 shows that the correlation between Rd and +b is negative, and their spatial patterns are the reverse. These relationships agree with the general perception that longer, stronger and

Table 3 Parameters of spherical models fitted to the experimental method of moments (MoM) variograms that describe the spatial structure of fiber quality properties in the study field (n = 66)[a]

Fiber quality properties	Range (m)	Nugget	Sill	Percentage nugget (%)[b]
Micronaire	156 (140)	0.037 (0.056)	0.13 (0.107)	28 (52)
Length (mm)	163 (159)	0.680 (0.440)	2.95 (3.16)	23 (14)
Uniformity (%)	101 (86)	1.02 (0.853)	1.80 (1.61)	56 (53)
Strength (g tex^{-1})	154 (128)	0.980 (1.09)	2.08 (1.70)	47 (64)
Elongation (%)	143 (134)	0.047 (0.049)	0.138 (0.120)	34 (41)
Rd	126 (120)	0.982 (0.730)	1.63 (1.64)	60 (45)
+b	126 (145)	0.016 (0.054)	0.28 (0.259)	5.3 (21)

[a] Parameters in parentheses are estimated from the residual maximum likelihood method (REML). They are listed in the table to examine the quality of the variogram models estimated by the method of moments estimator and weighted least squares fitting

[b] Percentage nugget is calculated as Nugget/Sill × 100

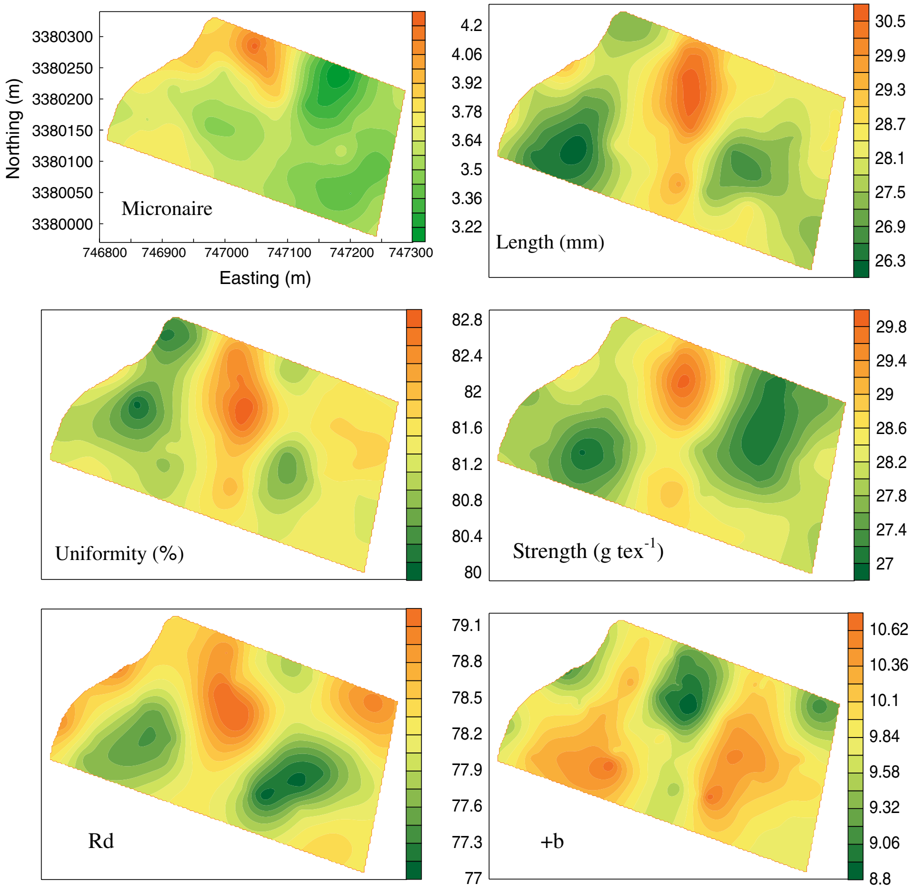

Fig. 3 Contour maps of block kriged estimates of selected fiber quality properties in the study field

Table 4 Pearson's correlation coefficients among fiber quality properties in the study field (n = 66)

	Length (mm)	Uniformity (%)	Strength (g tex^{-1})	Elongation (%)	Rd	+b
Micronaire	ns	ns	ns	ns	ns	ns
Length		0.72	0.62	−0.73	0.53	−0.72
Uniformity			0.49	−0.42	0.38	−0.50
Strength				−0.52	0.35	−0.53
Elongation					−0.50	0.62
Rd						−0.69

ns: not significant at the 0.01 level

brighter fibers tend to coincide, reflecting superior fiber quality and probably more favorable growing conditions. The distinct spatial pattern of micronaire indicates that it might respond to the growing environment differently from other fiber properties.

Figure 4 shows a map of soil apparent electrical conductivity (EC_a) of the study field measured with an electromagnetic induction sensor (EM-38, Geonics Ltd., Mississauga, Ontario, Canada) and a survey quality GPS receiver (Ag 114, Trimble). Without considering the field boundary areas, the spatial pattern for EC_a is similar to that of the fiber quality properties except for micronaire. Particular attention should be paid to the north central area with large EC_a values, which coincides with the area of superior fiber quality. In the non-saline soil of the study field, EC_a is strongly correlated with soil water holding capacity. Therefore it is reasonable to speculate that soil moisture availability might have been the major limiting factor for cotton during the season, and through proper water management fiber quality could be improved.

Loan rate maps associated with cotton fiber quality

According to the USDA (2001), cotton premiums or discounts (i.e. offsets from the base loan) are based primarily on four separate components. Three are determined by

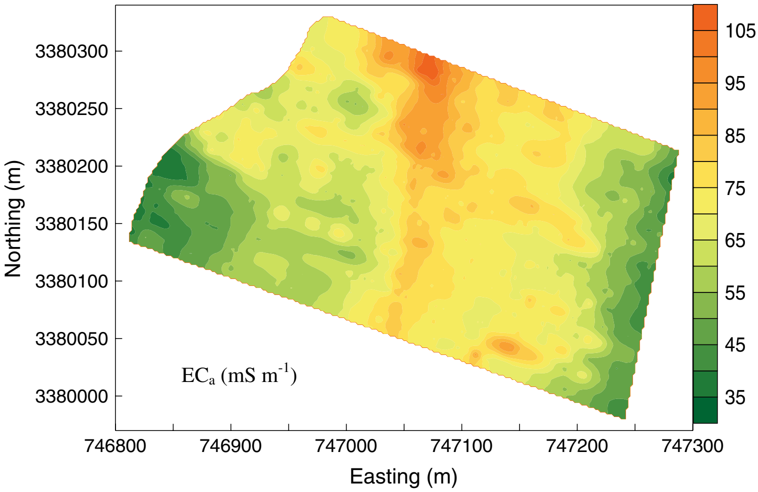

Fig. 4 Map of apparent soil electrical conductivity (EC_a) in the study field

micronaire, strength and uniformity, and one is determined jointly by length and color and leaf grades. These four components are the basis for mapping loan rate, and to achieve this they need to be incorporated as layers in a GIS. Layers for micronaire, uniformity and strength were converted directly from the corresponding maps in Fig. 3. The layer for length and color and leaf grades was generated as follows: (1) the price component of each sample point was determined from the sample measurement of length and color and leaf grades; (2) to produce the layer, values were interpolated to the same grid and over the same block size (2 × 2 m) as the other layers.

The four component layers for loan rate were overlaid in a GIS to give a map of overall loan rate associated with fiber quality (Fig. 5). The schedule of loan rate varies from year to year and the one specified for the 2006 crop (base loan is \$1.15 kg^{-1}, USDA 2007) was used here. Based on this, the loan rate associated with fiber quality varies from a discount of 5 cents kg^{-1} to a premium of 15 cents kg^{-1}. Again, the spatial distribution of loan rate is similar to that of EC_a, showing how field conditions can affect cotton fiber quality and potentially a producer's revenues.

The loan rate associated with fiber quality has a range of more than 20 cents kg^{-1}; this is a level of price variation that could have important economic implications for farmers. Figure 5 shows that more than half of the field produced relatively low-quality fibers that would have resulted in lower prices (red, orange and yellow hues), whereas the rest of the field produced relatively high-quality fibers that would have received higher premiums (blue and green hues). Assuming an average lint yield of 1135 kg ha^{-1} and a 10 cent kg^{-1} average price difference (half of the maximum price difference) between the high and low quality fibers, a benefit of \$114 ha^{-1} could be gained if the areas with poorer quality fibers could be improved to match the quality of the other areas. This would mean a difference in revenue of \$684 for this 12 ha study area (\$114 × 12 ha/2). Extrapolating this; if a farmer had 1000 ha of cotton fields under similar circumstances, he could obtain an increase in revenue of \$57 000 by improving fiber quality alone. This calculation assumes that high quality fibers can be achieved uniformly throughout the field. This is almost impossible in real situations, but it is a good starting point to show the importance of fiber quality in the

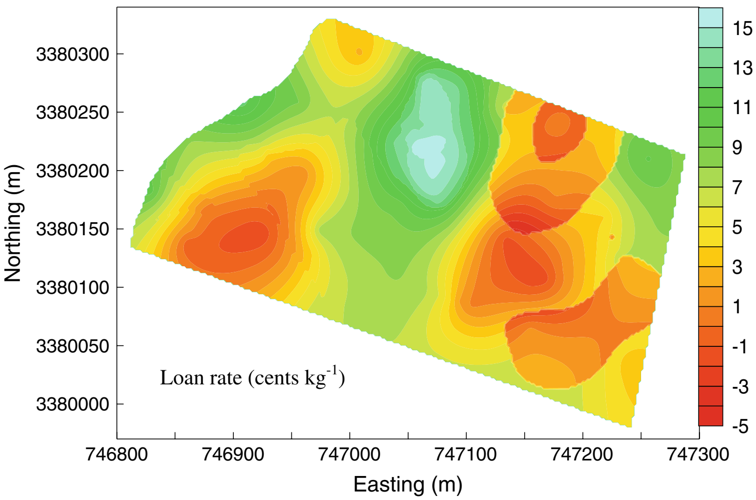

Fig. 5 Fiber quality associated loan rate map (offset from base loan rate of \$1.15 kg^{-1}) in the study field

field. An SSCM system that could encompass not only lint yields but also fiber quality to improve farmers' revenue and possibly profit is clearly needed.

Applications of fiber quality maps and caveats

In traditional SSCM, emphasis is often given to areas having high yield potential. With fiber quality maps, producers should be able to understand their crop and the financial ramifications of their management decisions better. Attention should also be paid to the interaction of yields and fiber quality. Even though a field area can have a high lint yield, low fiber quality could substantially lower the price paid for the cotton and reduce profitability there. On the other hand, some areas with low yield potential might still be profitable due to superior fiber quality. One of the future possibilities is to combine fiber quality maps with yield maps (such as those generated with a cotton yield monitor) to produce a revenue map. Taking this a step further; a net profit map could be produced if seasonal agronomic inputs (this information could be either uniform or site-specific) are known. The farmer would know from the net profit map from which parts of the field he/she is making a profit or a loss. If certain parts of the field that continually yield a negative net profit were identified in the long run (over several years), the farmer might consider excluding them from cotton production. Another possible application of fiber quality maps involves in situ fiber segregation during harvest so that fibers with superior quality could be aggregated and sold at a higher price.

It must be pointed out that for this study the fiber quality and loan rate maps were based on hand-harvested cotton samples. The samples were not stored in a module, and were processed with laboratory gins that have different machine sequences from commercial gins with respect to seed cotton cleaning and lint cleaning. In other words, the cotton in this study did not go through a typical commercial line of harvest, storage and processing that could degrade fiber quality and reduce value. Thus, it is important to note that the results of this study are useful in reflecting the degree of variation in fiber quality and the loan rate associated with it, but they are probably slightly different in terms of the absolute fiber quality values from what they would have been if the cotton had been produced under commercial practices.

Conclusions

An experiment was conducted in a dryland cotton field in Texas, USA to determine the spatial variation of cotton fiber quality and the loan rate associated with it. The major conclusions drawn from this study are as follows:

- Conventional statistics (such as the CV) showed that the within-field variation in fiber quality was economically significant. However, the degree of variation was generally low compared to that of lint yields.
- Variogram analysis showed that all fiber quality properties were spatially dependent, indicating that geostatistics would be more appropriate than conventional statistics for characterizing the variation in fiber quality at the field level.
- Contour maps of length, uniformity, strength, and Rd showed a similar spatial pattern (indicating positive correlations among them); and all of them showed the reverse pattern with +b (indicating negative correlation). Micronaire exhibited a different spatial pattern from the other fiber quality properties.

- A similar spatial pattern was observed between soil EC_a and some fiber quality properties, suggesting that soil EC_a, and therefore soil water holding capacity, could have had an important effect on fiber quality.
- The loan rate associated with fiber quality varied by as much as 20 cents kg^{-1} in the study field. This level of variability justifies a site-specific management system devoted to fiber quality to increase farmers' revenue.

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