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INFLUENCE OF SOIL MOISTURE CONTENT UPON COTTON FIBER QUALITY FOR BOTH IRRIGATED AND RAIN-FED COTTON

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Abstract

In-season soil moisture content is recognized as an important factor relating to post-harvest cotton fiber quality. Soil moisture can be controlled by irrigation, which is the most practical tool available to farmers in controlling the growth of cotton. The objective of this study is to quantify the relationship between post-harvest cotton fiber quality and in-season soil moisture content for both irrigated and rain-fed regimes. The experiment was conducted on the 130.27-ha Texas A&M University Research Farm. Three 0.25-ha regular grids were laid out in both irrigated and dry areas. Weekly soil moisture content was measured and 2 lbs of seedcotton was hand picked from the 76 sampling points (40 irrigated and 36 non-irrigated) in these grids. Seedcotton was ginned with a laboratory saw gin, and subjected to HVI testing to obtain fiber quality measurements. Significant correlation can be found between cotton fiber properties (fiber length, strength, and micronaire) and weekly soil moisture content. However, the correlation patterns were different in the irrigated and dry areas. Principal component regression analysis was applied to quantify the relationship between cotton fiber properties and weekly soil moisture content. Models developed from principal component scores of soil moisture content successfully predicted all three cotton fiber properties in both irrigated and dry areas. However, the regressors entered into the models were different when different areas were considered.

Introduction

Unlike most of the major agricultural commodities whose value was dominantly determined by crop yields, the value of cotton lint was determined by two equal components: lint yields and fiber quality. Until recently, more emphasis was stressed on cotton fiber quality for both cotton breeders and textile processors to meet the technological advances of yarn spinning and fabric processing, and increasing quality requirements for cotton end products. As Bradow and Davidonis (2000) summarized: “It is the quality, not quantity, of cotton fibers that determines the efficiency of spinning and dyeing and the quality of end products, and subsequently, the money returns for both cotton growers and textile processors”.

Along the vertical lifetime of cotton fiber from growing to processing, cotton fiber quality is studied at several different levels. At the bale level, studies occurred in warehouses and textile mills to develop predictive models for bale selection, fiber blending, and fiber-processing success (Chewning, 1995). At the plant level, extensive studies occurred in laboratories and fields to explore fiber quality distributions at different fruiting sites (Bradow et al., 1997). At the field level, there were many studies that dealt with fiber quality in-field variability and its associations with soil physical and chemical properties (Johnson et al., 2002; Ping et al., 2004).

Numerous studies in the past few decades have identified soil moisture content as one of the most important factors that would potentially affect post harvest cotton fiber quality and addressed how cotton fiber properties are modified by soil moisture deficit (Singh and Bhan, 1993; Hearn 1994; Shimishi and Marani, 1971; Marani and Amirav, 1971). In an attempt to correlate cotton fiber properties to soil properties, Johnson et al. (2002) found that soil moisture was strongly correlated with all cotton fiber properties (at the significant level of 0.05) except for micronaire and perimeter. However, like in Johnson et al. (2002) and Ping et al. (2004), many studies only did one-time soil moisture content measurement. In fact, soil moisture content was among the most unstable soil properties and varied greatly due to irrigation and precipitation. This project will address this issue to explore the relationship of cotton fiber quality and soil moisture content during the entire cotton growing season.

In the precision agriculture and cotton production communities there has long been concerns about applying variable rate irrigation, both spatially and temporally, to maximize lint yields and optimize cotton fiber quality. Towards this ultimate goal, there are some problems that should be solved. Firstly, the in-field variability of cotton fiber quality and soil moisture content should be verified, which will justify variable rate irrigation. Secondly, the relationship between cotton fiber quality and soil moisture content should be quantified so that variable rate irrigation strategy can be developed. The primary objective of this study was to statistically examine relationships between post harvest cotton fiber quality and in season soil moisture content at the field level.

Materials and Methods

Experiment Design

The field experiment was conducted on the Texas A&M Research Farm (also referred to as the Impact Center), in Burleson County (latitude 30.52975837, longitude -96.43629137), about 16.0 km southwest of College Station, Texas during the cotton growing season (from April to September) of 2005. The entire field covers an area of 130.27 ha (321.9 ac). Historically, the field was divided into six irrigation zones (*I1* through *I6*) and eight dry zones (*D1* through *D8*) for research and management purposes. The six irrigation zones were under the coverage of a center pivot irrigation system. In the year of 2005, cotton was grown on zone *I1*, *I2*, *I4*, *I5*, *D1*, *D3*, and *D4*.

Three 0.25-ha (50-m interval roughly) regular grid systems containing totally 86 sampling points were laid out, covering portions of the two irrigation areas (*I1* and *I2*) and two dry areas (*D1* and *D4*), for data collection. Because the purpose of this research was to study the relationship between in-season soil moisture content and post-harvest cotton fiber quality, the grids were intentionally placed on the areas with different soil moisture content ranges, which were created by different water application treatments (rainfed versus irrigation). Other factors that would potentially modify post-harvest cotton fiber quality (such as variety and seeding rate etc.) among these sample points should be kept as homogenous as possible. Table 1 listed the planting facts of the four areas on which the sampling points were laid out. The ten sampling points (Point # 41 – 50) on *D4* area were excluded from data analysis because its cotton variety and treatment were different from those of *I1*, *I2*, and *D1*, which might bias the analysis results. Subsequently roughly equal numbers of sampling points were from the irrigated (40 points) and dry areas (36 points).

Table 1. Planting facts for irrigated and dry areas

Area	Planting dates	Variety	Seeding rate (ac.$^{-1}$)	Row spacing (in.)	Treatment
I1	Apr. 13th – 14th	DP444 BR	52,000	30	Cruiser
I2	Apr. 13th – 14th	DP444 BR	52,000	30	Cruiser
D1	Apr. 15th	DP444 BR	52,000	40	Cruiser
D4	Apr. 12th – 13th	Fibermax 960 BR	52,000	30	Temick 4 lb ac^{-1}

The position of each sampling point was established by using a Global Positioning System (GPS) receiver with WAAS (Wide Area Augmentation System) correction (iFINDER™, Lowrance Electronics, Inc.). The GPS receiver has a nominal horizontal accuracy of 2-3 m. This level of accuracy was good enough for this field level study. For the first field visit, each sampling point was found as indicated by the GPS receiver and a flag was then placed permanently to facilitate position identification in the future.

Soil moisture content at each sampling point was measured on a weekly basis (once a week) from June 5th to August 27th (12 weeks). An ML2X ThetaProbe Soil Moisture Sensor (Dynamax Inc, U.S.A.; Delta-T Devices, U.K.) was used to measure soil moisture content and an HH2 Moisture Meter (Dynamax Inc, U.S.A; Delta-T Devices, U.K.) was used for data logging. The sampling devices of the ThetaProbe Soil Moisture Sensor are four rods, which sample a cylinder of 40-mm in diameter, 60-mm long soil bulk and measure the volumetric ($m^3.m^{-3}$) soil surface moisture content at a depth of 30 mm. The nominal accuracy of the sensor is ± 0.02 $m^3.m^{-3}$. Detailed technical specifications of both ThetaProbe Soil Moisture Sensor and HH2 Moisture Meter can be obtained from the user manual for "ML2X ThetaProbe" and "Moisture Meter type HH2".

At each sampling point, three soil moisture content readings were measured at three random locations within 2 m surrounding the flag. The locations were on the 2 neighboring cotton rows with the flag in the middle. Three measurements were then average and rounded to the nearest a hundredth as the volumetric soil moisture content reading at that sampling point. Note that because of the concurrent irrigation and heavy rainfall which made the cotton field waterlogged, the authors were unable to enter the irrigated areas to measure soil moisture content in

Week 4. Thus, only 11 weeks of soil moisture content data was available for the sampling points on the irrigated areas.

One week before the planned harvesting date (Aug 30th – Sept 1st), cotton samples were hand-harvested from the sampling points. Around two lbs of seed cotton was hand-harvested from each sampling point and placed in a numbered paper bag. To imitate the machine harvesting by a picker, the following sample strategies were applied: 1) only seed cotton from well cracked bolls were collected, 2) bolls from the top, middle, and bottom parts of the plants were collected to avoid boll position bias, 3) bolls harvested were from as many plants as possible within the 2-m range from the flag to avoid plant bias.

On Nov 8th, cotton samples were transported to the Cotton Production and Processing Research Unit at Lubbock, TX and ginned by a laboratory-scale saw gin. The cotton lint was then sent to the International Textile Center, Texas Tech University and subjected to HVI line testing. Among the nine reported cotton fiber properties, three of them (namely micronaire, fiber length, and fiber strength) were included in the following data analysis procedures.

Data analysis

Simple correlation analysis was performed (SAS PROC CORR) in an attempt to relate post harvest cotton fiber quality to in-season soil moisture content for the dry area, irrigated area, and two areas taken together. It was the authors' opinion that cross-area correlation would allow for more complete investigation over a wider range of soil moisture content. Pearson's correlation coefficients were determined for all in season soil moisture content and fiber quality combinations. In an attempt to use multiple linear regression analysis to develop models predicting cotton fiber quality by using in-season soil moisture content, there was some concern as to the strong correlation of soil moisture content among different weeks. To overcome this collinearity problem which might fail variable selection for model development, principal component analysis was performed on soil moisture data (SAS PROC PRINCOMP) to generate a set of orthogonal principal component scores. Stepwise regression analysis (MATLAB STATISTICAL TOOLBOX) was then performed on the principal component scores to develop models for cotton fiber properties. The p-value (probability of non-significance) for a variable to be added was set as 0.1 and the p-value for a regressor to be removed was set as 0.2. Comparing to SAS PROC REG, MATLAB STATISTICAL TOOLBOX provided the opportunity to diagnostically observe the effect of a variable upon the regression model when it was being included or eliminated. Again, three sets of models were developed for the dry area, irrigated area, and two areas combined. In order to make the models comparable, soil moisture content in Week 4 in the dry area was discarded before principal component analysis.

Results and Discussion

Correlation analysis

The Pearson's correlation coefficients between in-season soil moisture content and cotton fiber quality from the dry area, irrigated area, and two areas combined were presented in Table 1, Table 2, and Table 3, respectively. In the dry area, significant correlations existed among cotton fiber properties. Micronaire was negatively correlated with fiber length with the correlation coefficient of -0.49. Fiber length was positively correlated with fiber strength with the correlation coefficient of 0.79. Ping et al. (2004) also performed correlation analysis on 3-year cotton fiber quality data (micronaire, fiber length, and strength). Our results were consistent with their findings, which indicated negative correlation between micronaire and length, and positive correlations between fiber length and strength. Week soil moisture content can be divided into two groups. Group one included soil moisture content from Week 1 through Week 5 and Group two from Week 6 through Week 12. Generally, strong correlations existed within each group and no significant correlation can be found between two groups with only a few exceptions. Among three cotton fiber properties, only micronaire were significantly correlated with weekly soil moisture content in the dry area. It was negatively correlated with soil moisture content in Week 6, 9, 11, and 12. No significant correlation was found between other two cotton fiber properties and soil moisture content.

In the irrigated area, positive correlation can also be found between fiber length and strength (with the correlation coefficient of 0.66). The negative correlation between micronaire and fiber length found in the dry area did not exist. With respect to weekly soil moisture content, strong correlations can be found among weeks. However, the correlation pattern was quite different from that in the dry area. From Week 3 to Week 12, strong correlations can be found in almost all week pairs (except for Week 7). Different from the dry area, micronaire was positively correlated with soil moisture content in Week 10 in irrigated area. Fiber length was positively correlated with almost all of the weekly soil moisture content except for Week 2 and Week 7. Fiber strength was positively correlated with soil moisture content in Week 3, 5, 6, 10, and 11.

Table 1. Pearson's correlation coefficients amongst soil moisture content and fiber quality in dry area [a].

	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	Mic	Len	Str
W1	--	0.52	0.50	0.46	0.62										
W2		--	0.66	0.43	0.57										
W3			--	0.54	0.73	0.48	0.52	0.51		0.46					
W4				--	0.65										
W5					--			0.45							
W6						--	0.94	0.84	0.56	0.45	0.80	0.74			
W7							--	0.91	0.57	0.55	0.77	0.70			
W8								--	0.52	0.43	0.68	0.61			
W9									--		0.58	0.65			
W10										--					
W11											--	0.79			
W12												--			
Mic						-0.51			-0.51		-0.73	-0.55	--	-0.49	
Len														--	0.79
Str															--

a The correlation coefficients included were significant at 0.01 level.

Table 2. Pearson's correlation coefficients amongst soil moisture content and fiber quality in irrigated area [a].

	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	Mic	Len	Str
W1	--			--				0.44							
W2		--		--	0.48		0.50								
W3			--	--	0.60	0.81		0.76	0.64	0.66	0.74	0.69			
W4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W5				--	--	0.72		0.66	0.64	0.65	0.53	0.54			
W6				--		--		0.83	0.61	0.73	0.69	0.68			
W7				--			--								
W8				--				--	0.71	0.63	0.73	0.70			
W9				--					--	0.52	0.64	0.79			
W10				--						--	0.68	0.54			
W11				--							--	0.78			
W12				--								--			
Mic				--						0.48			--		
Len	0.43		0.78	--	0.54	0.75		0.67	0.65	0.69	0.65	0.65		--	0.66
Str			0.43	--	0.48	0.54		0.42		0.69	0.46				--

a The correlation coefficients included were significant at 0.01 level.

Table 3. Pearson's correlation coefficients amongst soil moisture content and fiber quality in areas combined [a].

	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	Mic	Len	Str
W1	--	0.47	0.78	--	0.77	0.39		0.62		0.37	0.59	0.45			
W2		--	0.59	--	0.66	0.34		0.41		0.33	0.41				
W3			--	--	0.91	0.59		0.77		0.43	0.81	0.62			
W4	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W5				--	--	0.57		0.75		0.42	0.75	0.59			
W6				--		--	0.39	0.83	0.42	0.63	0.74	0.75			
W7				--			--	0.31	0.34						
W8				--				--	0.34	0.56	0.82	0.74			
W9				--					--	0.31		0.46			
W10				--						--	0.51	0.49			
W11				--							--	0.82			
W12				--								--			
Mic			-0.33	--							-0.37	-0.32	--		
Len				--		0.5		0.33	0.46	0.34	0.39	0.48		--	0.58
Str	-0.34		-0.42	--	-0.40				0.31						--

a The correlation coefficients included were significant at 0.01 level.

When the sampling points in both dry and irrigated areas were taken collectively, positive correlation can still be found between fiber length and strength. No significant correlation can be found between micronaire and other two fiber properties. Significant positive correlation can be found among weekly soil moisture content. However, the special patterns shown in Table1 and Table 2 did not exist. Although significant correlations can still be found between cotton fiber quality and weekly soil moisture content, the amplitude of correlation coefficients became much smaller. This agreed with the conclusion from other precision agriculture studies which found the degree of correlation between two variables tended to decrease if larger geographical regions were considered. Micronaire was negatively correlated with soil moisture content in Week 3, 11, and 12. Fiber length was positively correlated with soil moisture content in Week 6, 9, 10, 11, and 12. Fiber strength was positively correlated with soil moisture content in Week 9 and negatively correlated with soil moisture content in Week 1, 3, and 5.

Regression Analysis

Table 4. Prediction models for cotton fiber quality in dry area, irrigated area, and areas combined.

Fiber properties	Dry area			Irrigated area			Areas Combined		
	Regressors	R^2	rmse (%)	Regressors	R^2	rmse (%)	Regressors	R^2	rmse (%)
Micronaire	PC1, PC2, PC3, PC5,	0.68	2.9	PC1, PC5, PC6,	0.32	4.1	PC1, PC4, PC7, PC8	0.39	4.3
Length	PC2, PC5, PC6	0.43	2.6	PC1, PC2	0.66	1.9	PC1, PC2, PC3, PC6	0.41	2.7
Strength	PC2, PC4, PC5, PC6	0.42	3.8	PC1, PC2, PC3, PC7	0.42	2.7	PC1, PC2, PC3, PC6,	0.43	3.9

It can be seen from correlation analysis that significant correlations existed among weekly soil moisture content. If directly used, it would cause multi-collinearity problem and might fail variable selection procedure in regression analysis. Thus principal component analysis was performed to de-correlate soil moisture content data and stepwise regression analysis was applied on the orthogonal principal component scores (also known as principal component regression).

The result of regression analysis between fiber quality and principal component scores was summarized in Table 4. Clearly, principal component scores successfully predicted cotton fiber quality in the dry, irrigated, and combined areas. Among the nine models, seven of them contained regressors from the first six principal components. The only exceptions were with the fiber strength model in the irrigated area (PC7) and the micronaire model in the combined area (PC7 and PC8). Adjusted R^2 and rmse values were reported in Table 4 to evaluate the prediction capability of the models. The best model to predict fiber properties in the dry area was the micronaire model, which had the lowest rmse value and the highest adjusted R^2 value. The best model in the irrigated area was the fiber length model. When the dry area and the irrigated area were taken together, the prediction capability of all three models decreased. Although the micronaire model in combined area had higher adjusted R^2 value than that in the irrigated area, the rmse value in combined area was also higher than that in the irrigated area. This again verified that in precision agriculture studies, the relationship among variables were more difficult to quantify when larger geographical regions were considered.

Conclusions

The important conclusions drawn from this study were as follows:

1. Strong correlations can be found among cotton fiber properties, among weekly soil moisture content, and between cotton fiber quality and weekly soil moisture content in both irrigated and dry areas.
2. Strong correlations between cotton fiber quality and soil moisture content can still be found when the sampling points in the irrigated and dry areas were combined. However, the amplitude of correlation diminished.
3. Models developed from principal component scores of soil moisture content successfully predicted all three cotton fiber properties in both irrigated and dry areas. However, the regressors entered into the models were different when different areas were considered.

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