EFFECTS OF SUPPLEMENTAL IRRIGATION AND NITROGEN ON COTTON YIELD AND FIBER QUALITY

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Abstract

Effects of supplemental irrigation and nitrogen (N) fertilization on cotton yield and fiber quality were investigated in the Mississippi Delta in 2011 and 2012. Cotton was planted in 48 experimental plots with irrigation as the main treatment unit and N application rate as the sub-unit. Irrigation was scheduled based on soil moisture content measured using soil water sensors. Cotton was harvested with a spindle-type cotton harvester. The yield in each plot was determined using a load cell scale on a boll buggy. Seed cotton samples were ginned and the fiber quality was evaluated. Statistical analyses on the effects of irrigation and nitrogen on the yield and fiber quality indicated that irrigation increased cotton yield by 14%. Irrigation improved fiber quality, including length, UQL, fineness, maturity, UHML, short fiber content, and reflectance in the 2011 season, and UQL and UHML in 2012. An increase in neps in irrigated cotton was observed in 2011, but not in 2012. The effects of leaf N on neps, fineness, and maturity and the interaction of irrigation with N on these factors were significant in the 2011 season. Leaf N higher than the critical value (4%) did not improve yield. Excessive application of N could possibly create negative impacts on yield and environmental sustainability.

Introduction

There have been sufficient ground water resources in the Mid-South U.S., with average annual rainfall around 140 cm (55”), but precipitation patterns frequently include heavy precipitation events that increase runoff from cropland with only a small amount of rainfall left within the soil profile. This runoff can also cause nutrient loss from cropland, which has become an environmental issue. Uncertainty in the amount and timing of precipitation is one of the most serious risks to producers in the Mid-South. In recent years, producers have become increasingly reliant on supplemental irrigation to ensure adequate yields and reduce risks of production. Therefore, research to optimize crop water and nutrient management are necessary.

Cotton is one of the major crops in the Mid-South area. Both the yield and fiber quality of cotton are important factors in determining the producer’s profit. Producing high-yielding and high-quality cotton requires careful management in every production stage, including proper application of water and nutrients. Water stress in cotton plants can limit plant growth and productivity, resulting in reduction of yield (Cull et al. 1981). Under-fertilization and over-fertilization with nitrogen (N) can negatively affect the desired growth pattern of cotton plants, and thus degrade fiber quality and reduce yield (Fernandez et al., 1996; Gerik et al., 1998). Additionally, over-fertilization with N will increase production costs while increasing the potential for negative environmental impacts (Bakhsh et al., 2002; Potter et al., 2001).

The objective of this study was to investigate the effects of irrigation and nitrogen on cotton yield and cotton fiber quality.

Materials and Methods

Experimental Setup

A cotton field at a research farm of the USDA-ARS Crop Production Systems Research Unit in Stoneville, MS (latitude: 33°26'30.86", longitude: -90°53'26.60") was selected as an experimental site. There was an approximately 0.5% slope from the east side of the field to the west. Soil texture of the field varied from silt to silt loam. Forty-eight plots were laid out in the experimental field. Plots were 48.8 m long, 23.2 m wide, and contained 24 rows. A 7.7 m-wide buffer was used between the plots. One soil sample from each plot was collected in the 2011 season before planting and analyzed for residual N and textural properties at the Mississippi State University Extension Service Soil Testing Laboratory in Starkville, MS (Table 1).

Table 1. Soil textural properties of the experimental plots.

Plot No.	Clay %	Silt %	Sand %	Texture	Plot No.	Clay %	Silt %	Sand %	Texture
101	2.50	76.50	21.00	Silt Loam	**301**	5.00	78.50	16.50	Silt Loam
102	2.50	75.25	22.25	Silt Loam	**302**	7.50	83.25	9.25	Silt
103	2.50	78.75	18.75	Silt Loam	**303**	7.50	84.00	8.50	Silt
104	2.50	77.75	19.75	Slit Loam	**304**	5.00	85.00	10.00	Silt
105	3.75	78.50	17.75	Silt Loam	**305**	5.00	82.00	13.00	Silt
106	6.25	76.50	17.25	Silt Loam	**306**	5.00	82.25	12.75	Silt
107	1.25	80.25	18.50	Silt	**307**	10.00	80.50	9.50	Silt
108	1.25	77.00	21.75	Silt Loam	**308**	13.75	81.75	4.50	Silt Loam
109	1.25	77.00	21.75	Silt Loam	**309**	16.25	78.50	5.25	Silt Loam
110	5.00	82.00	13.00	Silt	**310**	20.00	76.00	4.00	Silt Loam
111	3.75	79.75	16.50	Silt Loam	**311**	15.00	70.75	14.25	Silt Loam
112	7.50	79.25	13.25	Silt Loam	**312**	10.00	77.50	12.50	Silt Loam
201	3.75	74.25	22.00	Silt Loam	**401**	8.75	82.75	8.50	Silt
202	2.50	80.00	17.50	Silt	**402**	16.25	80.50	3.25	Silt Loam
203	1.25	78.50	20.25	Silt Loam	**403**	17.50	80.25	2.25	Silt Loam
204	3.75	77.75	18.50	Silt Loam	**404**	17.50	78.25	4.25	Silt Loam
205	2.50	77.75	19.75	Silt Loam	**405**	18.75	77.25	4.00	Silt Loam
206	2.50	75.50	22.00	Silt Loam	**406**	8.75	78.75	12.50	Silt Loam
207	3.75	80.50	15.75	Silt	**407**	17.50	76.75	5.75	Silt Loam
208	5.00	82.25	12.75	Silt	**408**	18.75	78.25	3.00	Silt Loam
209	6.25	82.00	11.75	Silt	**409**	21.25	76.50	2.25	Silt Loam
210	5.00	79.00	16.00	Silt Loam	**410**	7.50	89.50	3.00	Silt
211	3.75	73.00	23.25	Silt Loam	**411**	21.25	76.25	2.50	Silt Loam
212	10.00	83.25	6.75	Silt Loam	**412**	5.00	78.75	16.25	Silt Loam

A split plot design was used in the study with 2 irrigation treatments (irrigated and non-irrigated) as the main unit and 6 nitrogen treatments (0, 39, 67, 101, 135, and 168 kg/ha) as the subunit. The main unit design was a randomized complete block (RCB) with 2 blocks. There were 2 replications (blocked) of the subunit within each main unit. This resulted in 12 plots in each block and 48 plots in total. One N application rate was randomly assigned to each plot.

In 2011, DP 0912 B2RF (Monsanto, St. Louis, MO) was planted on May 8. Row spacing was 0.97 m. Nitrogen in the designated rate was applied to each plot using a side knife drill on June 24. Irrigation water was applied to alternate furrows using a poly-pipe system. The irrigated plots were irrigated twice during the 2011 season based on soil water content measured using soil moisture sensors: 5 cm of water was applied on July 6 and 7.6 cm on July 20. In the 2012 season, the same cotton cultivar was planted on April 26 and the N fertilizer was applied on June 8. Total water depth of 16 cm (6.3") was applied at five irrigation events during the season using a center pivot sprinkler irrigation system.

Sample Collection and Analysis

Leaf samples were collected at early bloom stage. Ten uppermost fully expanded main-stem leaves were taken to make one leaf sample. Three leaf samples were randomly collected in each plot, resulting in 144 leaf-blade samples in total. Leaf samples were analyzed for N content using the Kjeldahl method at Mississippi State University

Extension Service Soil Testing Laboratory. The average of N content values of the three leaf samples from each plot was calculated to represent plant N status in the plot. In 2011, non-irrigated plots were defoliated on September 8, and irrigated plots on September 23. Cotton was machine harvested with a spindle-type picker on October 11. In 2012, non-irrigated plots were defoliated on August 21, and irrigated plots on September 7. Defoliant was applied again to non-irrigated plots on September 6. Non-irrigated plots were picked on September 27, and the irrigated on October 17. In the 2012 season, several rains occurred between defoliation and harvest. Seed cotton harvested from the 12 center-rows of each plot was weighed for yield determination. Approximately 38 kg of seed cotton were randomly collected from each plot during harvesting for fiber quality analysis.

The seed cotton samples were ginned at the USDA-ARS Cotton Ginning Research Unit (CGRU) at Stoneville, MS. The ginning sequence included a dryer, cylinder cleaner, stick machine, dryer, cylinder cleaner, extractor-feeder, gin stand, and saw-type lint cleaner. There was no heat added in the dryers in the ginning process. Thirteen sub-samples were collected after the lint cleaner from each sample, five of them for testing with Advanced Fiber Information System (AFIS), five for High Volume Instrument (HVI) and three for determining lint moisture content. Three sub-samples of seed cotton were taken before the gin stand for seed cotton moisture measurement. All lint samples were analyzed at the USDA-ARS SRRC (Southern Regional Research Center). Fiber quality parameters were measured with AFIS and HVI tests, including micronaire, fiber length, maturity, strength, elongation, color, and short fiber content. Moisture content of the seed cotton and lint was determined by the conventional oven method at the USDA-ARS CGRU at Stoneville, MS (Shepherd, 1972).

Data Analysis

An ANOVA was performed with SAS software using the PROC MIXED procedure (SAS Institute Inc., Cary, NC) to evaluate the effect of irrigation and leaf N on yield and fiber quality. In this analysis, irrigation treatment was a fixed effect; the block within irrigation treatment was a random effect and degrees of freedom calculations were based on Kenward/Roger option (Littell, Milliken, Stroup, Wolfinger, & Schabenberger, 2006).

One plot (No. 212) was flooded several times during the 2011 season due to accumulation of heavy rainfall and irrigation water caused by a water barrier built to prevent water traveling from the irrigated block to the non-irrigated plots. Excessive amounts of water in this plot resulted in undesirable growth patterns of plant biomass and caused shedding of cotton flowers and bolls, resulting in significant yield reduction. Yield data in 2011 from this plot was therefore treated as an outlier and removed from the data set when the data analysis was performed.

Results and Discussions

Seed Cotton Yield

In 2011, the mean seed cotton yield in non-irrigated plots was 2975 kg/ha (SD=309 kg/ha) with a maximum of 3421 kg/ha and a minimum of 2208 kg/ha. The seed cotton yield of irrigated plots ranged from 2851 kg/ha to 4417 kg/ha with a mean of 3399 kg/ha (SD=391 kg/ha). The ANOVA indicated that yield of irrigated plots was significantly higher than the yield of the non-irrigated ($F=17.02$, $p=0.0002$). Overall, supplemental irrigation increased seed cotton yield by 14.2% in the 2011 season. In the 2012 season, irrigation increased the yield by 13.4% with an average seed cotton yield of 2179 kg/ha (SD=400 kg/ha) in irrigated plots and 1921 kg/ha (SD=669 kg/ha) in the non-irrigated plots. In terms of percentage, yield increase caused by irrigation was similar in both years. However, the effect of irrigation on yield was statistically significant in 2011, but not in 2012 ($F=0.90$, $p=0.3754$).

Plant leaf N content in 2011 was in the range of 3.73% to 5.74% with an average of 4.97% (SD=0.50%) in irrigated plots and 4.53% (SD=0.25%) in non-irrigated plots. Variation of leaf N content in irrigated plots was greater than that in non-irrigated plots (Figure 1). A critical value of cotton leaf N at early bloom in the Mid-South U.S. is 4%, according to Bell et al. (1998), and cotton plants might be considered to be under N stress if leaf N concentrations are less than this value. There was only one plot where the plant leaf N was slightly lower than the critical value (3.73%). Due to the large amount of residual N in soil, cotton response to applied N rates was diminished in the 2011 season. The ANOVA result showed that the effect of leaf N on yield was not significant ($F=0.08$, $p=0.7774$). Correlation between leaf N and yield was very weak (Figure 1). This indicated that once cotton plants received sufficient N, excess application of N would not improve cotton yield. In the 2012 season, N application rate was used as a covariate in the data analysis instead of leaf N content. The ANOVA indicated that the effect of N rate on seed cotton yield was not significant ($F=1.43$, $p=0.2902$) in 2012.

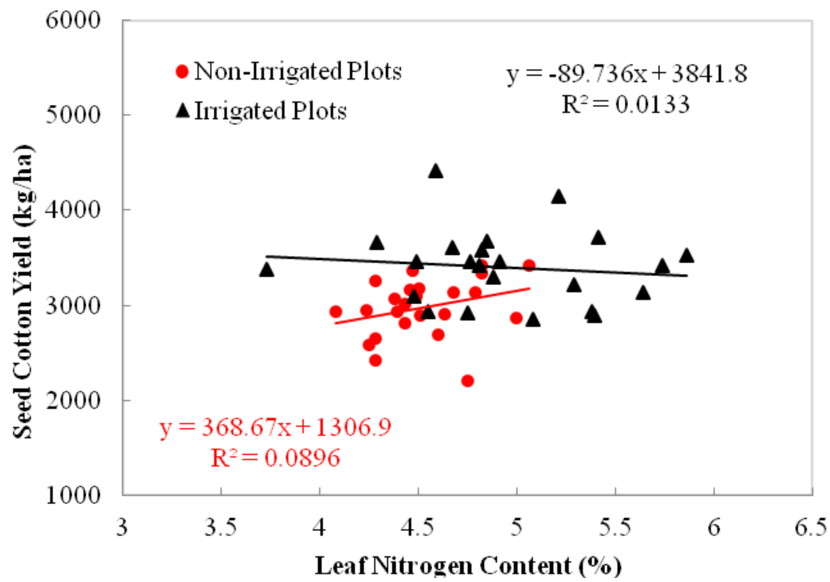

Figure 1. Relationship between plant leaf nitrogen content and yield for irrigated and non-irrigated plots in 2011.

Cotton Fiber Quality

A summary of sample moisture data is given in Table 2. In the 2011 season, seed cotton moisture content before the gin stand was 7.64% for irrigated cotton and 7.61% for the non-irrigated. Lint moisture after the lint cleaner was 4.44% for the irrigated and 4.46% for the non-irrigated. The ANOVA analysis revealed that moisture contents of irrigated cotton samples did not significantly differ from those of non-irrigated samples before the gin stand (F=0.02, p=0.8835) or after the lint cleaner (F=0.03, p=0.8693). In 2012, the moisture difference between irrigated and non-irrigated samples was significant. However, moisture content of all samples was in a range in which cotton fiber quality should not be significantly affected during the ginning process.

Table 2. Moisture content of samples collected before the gin stand and after the lint cleaner. Means with the same letter are not significantly different at the 0.05 level.

h area	Type	Treatment	Mean (%)	Max (%)	Min (%)	STDEV
2011	Seed Cotton	Irrigated	7.64[a]	9.38	6.35	0.72
		Non-irrigated	7.61[a]	8.87	5.69	0.86
	Lint	Irrigated	4.44[b]	4.82	3.93	0.28
		Non-irrigated	4.46[b]	5.18	3.78	0.31
2012	Seed Cotton	Irrigated	8.45[c]	9.35	7.68	0.42
		Non-irrigated	7.82[d]	9.21	6.77	0.58
	Lint	Irrigated	5.23[e]	5.90	4.52	0.41
		Non-irrigated	4.80[f]	5.23	4.48	0.24

Table 3 shows the results of the ANOVA test on AFIS fiber property measurements in 2011. Fiber length (L(w)), upper quartile length (UQL), nep count, dust count, fineness, and maturity differed significantly as a function of irrigation treatment at the 0.05 level while the SFC did not. Fiber length and UQL of irrigated cotton were greater than that of the non-irrigated cotton (Figure 2 and 3). Effect of leaf N on the length, UQL, and SFC was not significant. The ANOVA test also showed that effects of leaf N on nep, fineness, and maturity were significant while the effects on the other AFIS properties were not significant. Interaction of irrigation with plant leaf N was not significant for the length, SFC, and UQL. However, the interaction was significant with nep, dust, fineness, and maturity. This demonstrated that the effect of leaf N on those fiber properties depended on whether the plots were irrigated. Means of nep, dust, fineness, and maturity given in Table 3 were calculated using the mean of leaf N, which was 4.73%. Figures 4 and 5 respectively show dust and nep content versus leaf N with irrigation treatments. It was observed that the irrigated cotton had less dust than the non-irrigated (F=4.24, p=0.0426) (Figure 4), but the irrigated cotton had more neps than the non-irrigated (F=7.62, p=0.0088) (Figure 5).

Table 4 shows the results of the ANOVA test on AFIS fiber property measurements in 2012. The effect of irrigation on UQL(w) was significant (F=27.55, p=0.0006), but was not significant for the other AFIS properties in the 2012 season.

Table 3. Results of the ANOVA test for effect of irrigation and leaf N on AFIS fiber properties in 2011.

Fiber Property	Irrigation				Leaf N		Irrigation*Leaf N	
	Irrigated Mean	Non-Irr. Mean	F	p > F	F	p > F	F	p > F
L(w) (in)	0.98	0.96	23.06	<0.0001	0.9	0.3471	0.27	0.6091
SFC(w) (%)	7.64	7.52	0.34	0.6169	1.4	0.2431	1.97	0.1675
UQL(w) (in)	1.17	1.14	44.96	<0.0001	0.43	0.5167	0.91	0.3466
Nep (cnt/g)	228.66	204.60	7.62	0.0088	4.62	0.0378	6.44	0.0152
Dust (cnt/g)	280.23	350.91	4.24	0.0462	3.82	0.0577	4.93	0.032
Fine (mtex)	177.69	172.94	7.46	0.0091	6.64	0.0135	8.04	0.0069
MatRat	0.95	0.94	8.22	0.0069	5.79	0.0212	8.18	0.0069

Table 4. Results of the ANOVA test for effect of irrigation and leaf N on AFIS fiber properties in 2012.

Fiber Property	Irrigation				N Rate		Irrigation*N Rate	
	Irrigated Mean	Non-Irr. Mean	F	p > F	F	p > F	F	p > F
L(w) (in)	0.98	0.97	2.33	0.2664	1.83	0.1365	2.43	0.0579
SFC(w) (%)	8.07	8.26	0.07	0.8189	0.60	0.7034	1.73	0.1576
UQL(w) (in)	1.18	1.16	27.55	0.0006	2.44	0.0994	1.99	0.1567
Nep (cnt/g)	177.42	181.85	0.1	0.7777	0.64	0.6724	0.22	0.9515
Dust (cnt/g)	283.78	275.37	0.03	0.8848	0.55	0.7357	1.97	0.1114
Fine (mtex)	173.66	173.79	0	0.9839	0.27	0.9210	1.05	0.4399
MatRat	0.93	0.94	0.09	0.7941	0.43	0.8165	1.73	0.2145

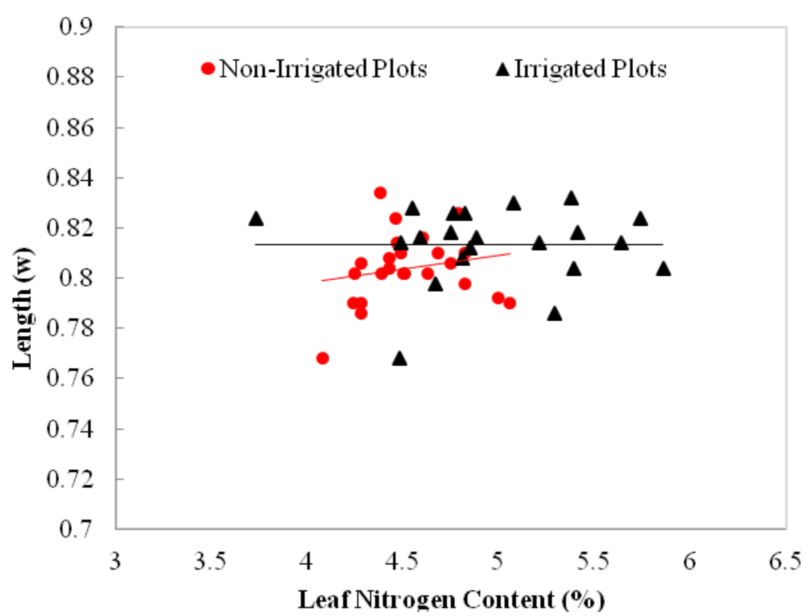

Figure 2. AFIS fiber length versus leaf N content in irrigated and non-irrigated plots.

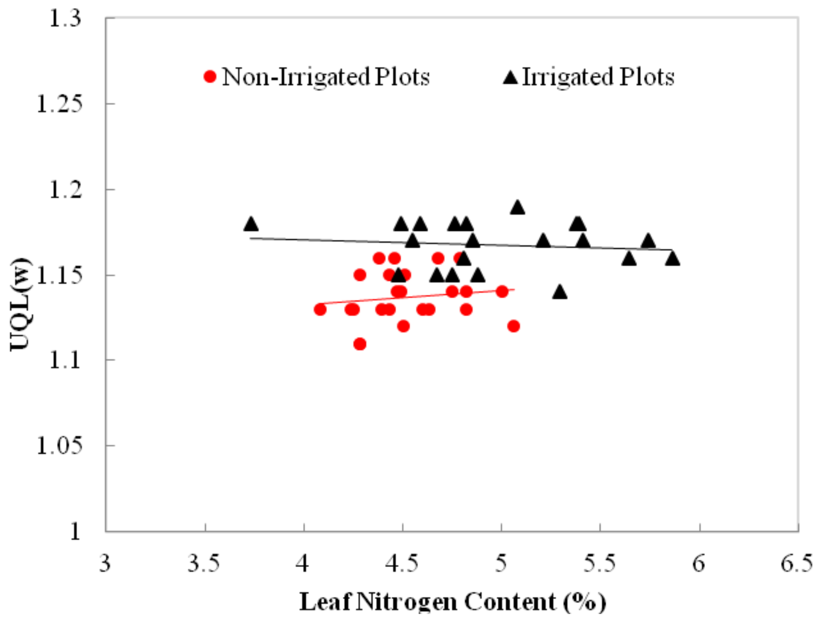

Figure 3. UQL Variation of irrigated and non-irrigated cotton.

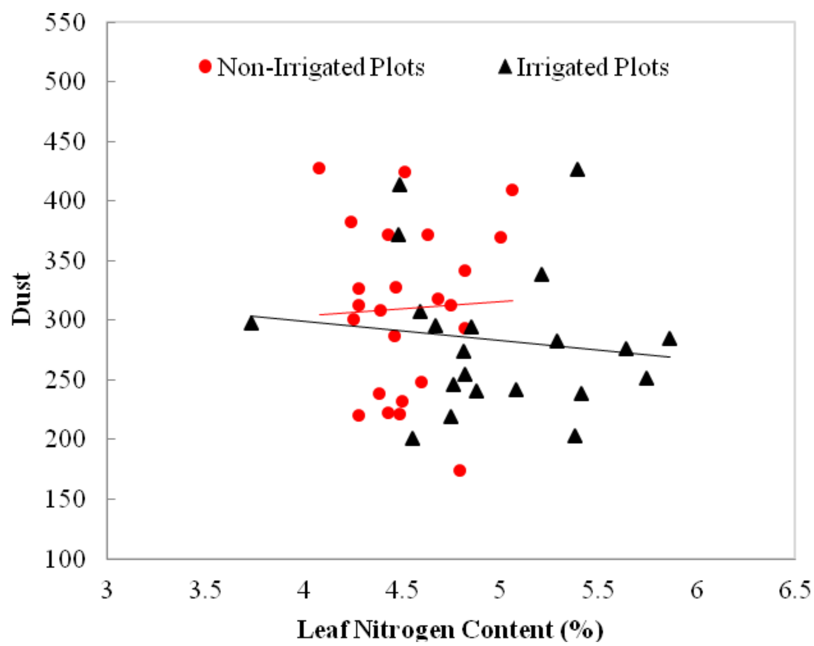

Figure 4. Dust content versus leaf nitrogen content in irrigated and non-irrigated plots.

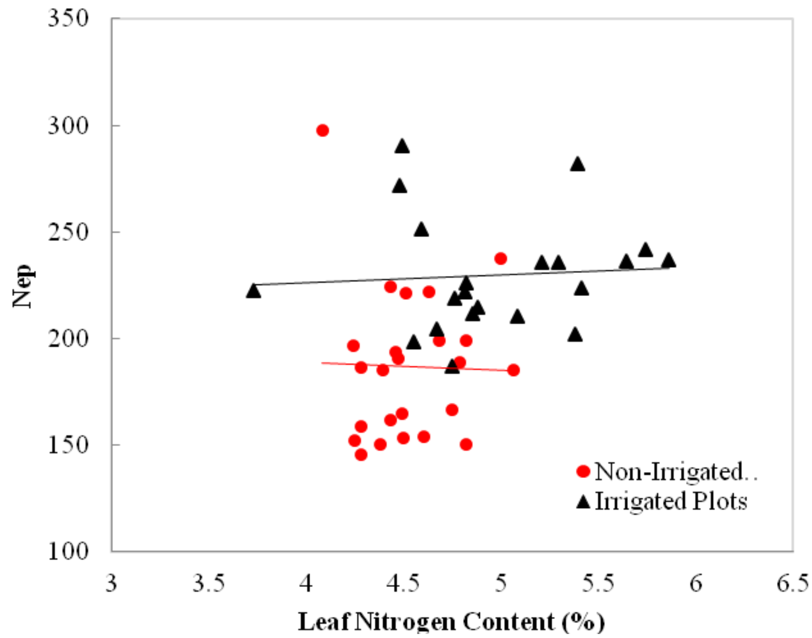

Figure 5. Nep content versus leaf nitrogen content.

The effects of irrigation and nitrogen on HVI fiber property were shown in Tables 5 and 6. In the 2011 season, the ANOVA test revealed that the effects of irrigation on micronaire, upper half mean length (UHML), short fiber content, reflectance (Rd), and trash area (TrAr) were significant. UHML of irrigated cotton (M=1.12) was slightly greater than that of non-irrigated cotton (M=1.09), but the difference was statistically significant (Figure 6). Short fiber content of the irrigated cotton (M=8.94) was lower than that of the non-irrigated (M=9.26%) (Figure 7). It was obvious that the irrigated cotton had a higher reflectance value (M=79.45) than the non-irrigated cotton (M=75.44) (Figure 8). The ANOVA results also indicated that the effects of irrigation on uniformity index (UI), strength, elongation, and yellowness (+b) were not significant. Micronaire, yellowness, and TrAr significantly differed as a function of leaf nitrogen. Interaction of irrigation and leaf N was significant in micronaire and TrAr. Effect of leaf N on micronaire and TrAr depended on irrigation. Means of micronaire and TrAr under irrigation treatments in Table 5 were determined with the mean of leaf N.

In 2011, the effect of irrigation on UHML in HVI measurements was consistent with that on fiber length and UQL in AFIS measurements, and effect on HVI's TrAr was reflected in the same trend as on the AFIS's dust measurement. However, in terms of short fiber content, the effect of irrigation was significant with the HVI test, but was not significant based on AFIS measurement. The ANOVA test on the 2012 data indicated no significant effect of irrigation and N rate on HVI properties except for UHML. The UHML of irrigated cotton was significantly greater than that of non-irrigated cotton (F=22.83, P=0.0411). Effect of N rate on UHML and the interaction of irrigation and N rate in UHML were significant as well. Although the effect of irrigation on short fiber content was not significant (Table 5), the short fiber of irrigated cotton was less than that of the non-irrigated.

Table 5. Results of the ANOVA test for effect of irrigation and leaf N on HVI fiber properties in 2011.

Fiber Property	Irrigation				Leaf N		Irrigation*Leaf N	
	Irrigated Mean	Non-Irr. Mean	F	p > F	F	p > F	F	p > F
Mic	4.37	4.32	5.48	0.0244	6.06	0.0183	5.38	0.0255
UHML (in)	1.12	1.09	17	0.0541	0.21	0.6521	1.14	0.2911
UI (%)	82.27	81.63	13.22	0.068	0.03	0.8555	0.34	0.561
SF (%)	8.94	9.26	27.48	0.0345	0.18	0.6763	0.11	0.7444
Str (g/tex)	30.53	31.05	2.14	0.2809	0.52	0.4769	0.23	0.633
Elg (%)	6.25	5.93	4.46	0.1692	1.33	0.2556	0.11	0.7403
Rd	79.45	75.44	67.19	0.0146	0.68	0.4133	1.98	0.1669
+b	7.69	7.50	1.35	0.3596	5.19	0.0278	0.45	0.5086
TrAr (%)	0.35	0.49	5.39	0.0251	7.65	0.0083	7.01	0.0113

Table 6. Results of the ANOVA test for effect of irrigation and leaf N on HVI fiber properties in 2012.

Fiber Property	Irrigation				N Rate		Irrigation*N Rate	
	Irrigated Mean	Non-Irr. Mean	F	p > F	F	p > F	F	p > F
Mic	4.81	4.60	1.82	0.3095	0.4	0.8466	0.68	0.6495
UHML (in)	1.11	1.09	22.83	0.0411	4.84	0.0023	3.51	0.0128
UI (%)	81.47	81.38	0.07	0.8174	0.77	0.5746	0.91	0.511
SF (%)	8.70	9.57	1.73	0.3186	0.94	0.4655	1.04	0.4144
Str (g/tex)	29.60	29.11	0.82	0.4606	0.5	0.7728	1.6	0.2468
Elg (%)	6.40	6.41	0.02	0.8974	0.28	0.918	1.5	0.2701
Rd	74.78	76.05	1.86	0.3061	0.81	0.549	1.86	0.3061
+b	7.03	7.17	0.21	0.694	0.86	0.5192	0.21	0.694
TrAr (%)	0.295	0.289	0.03	0.8717	1.59	0.2232	0.81	0.5685

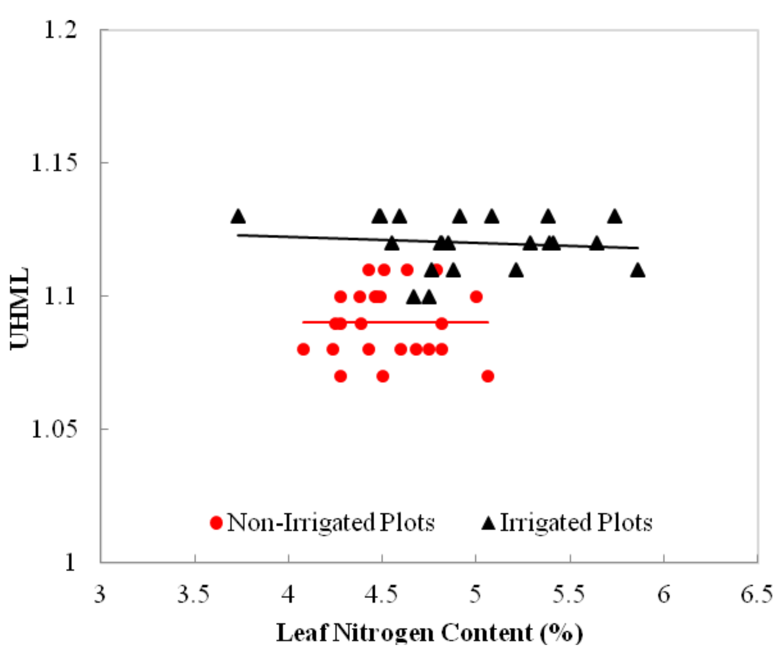

Figure 6. UHML difference between irrigated and non-irrigated plots.

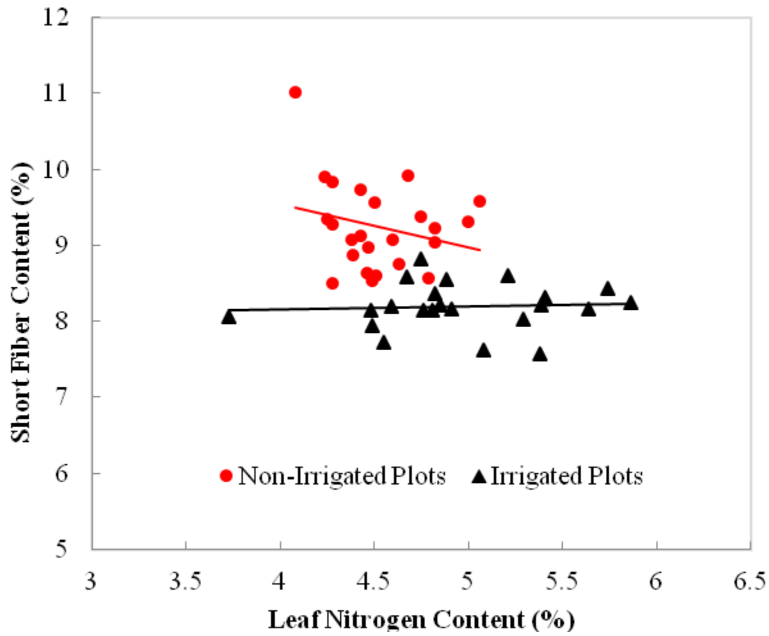

Figure 7. Irrigated cotton had less short fiber content than the non-irrigated cotton.

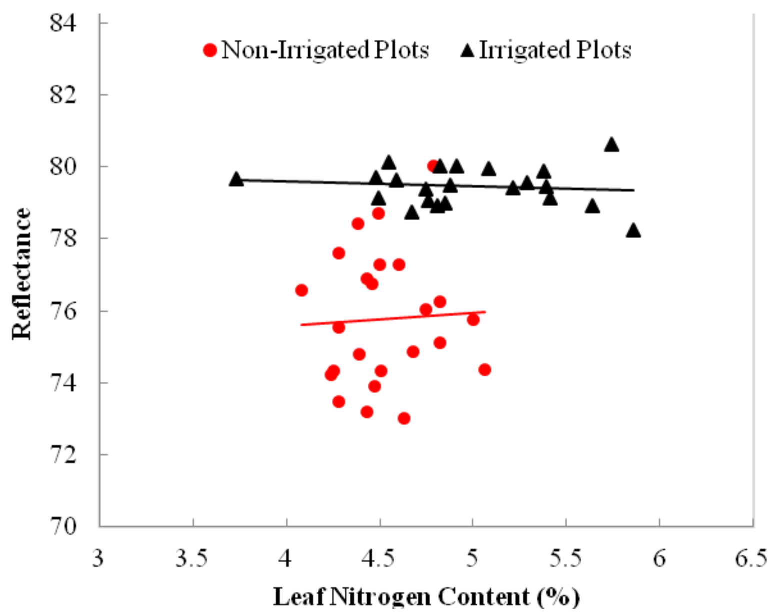

Figure 8. Irrigated cotton had higher reflectance than the non-irrigated cotton.

Conclusions

Experiments were conducted in Stoneville, MS to investigate the effect of supplemental irrigation and N fertilization on yield and fiber quality in cotton. It was found that supplemental irrigation increased seed cotton yield by 14% in year 2011 and 2012. In the 2011 season, effects of irrigation on cotton fiber properties, including fiber length, nep, dust, fineness, maturity, micronaire, short fiber content, Rd, and TrAr, were significant. Fiber properties, including fiber length, short fiber content, and reflectance were slightly improved by irrigation. However, it was observed that the nep content of irrigated cotton was significantly higher than the non-irrigated cotton in the 2011 season, but not in 2012. Effects of irrigation on UQL and UHML were significant in 2011 and 2012. Leaf N had a significant effect on the nep, fineness, maturity, micronaire, yellowness, and TrAr. The fineness and maturity of the non-irrigated cotton showed a decreasing trend as leaf N increased. Excessive N application did not have a positive impact on the yield.

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