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AGRONOMY AND SOILS

Effect of Nitrogen Application Rates on Yield and Quality in Irrigated and Rainfed Cotton

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ABSTRACT

Studies on the effect of nitrogen (N) application rates on lint yield and fiber quality in irrigated and rainfed cotton were conducted for two years. In 2013, cotton was planted in 48 plots. Twenty-four plots were irrigated and the other 24 pots were rainfed. Six N application rates (0, 39, 67, 101, 135, and 168 kg/ha) with four replicates were randomly assigned to the irrigated and rainfed plots. In 2014, five N treatments (0, 56, 112, 168, and 224 kg/ha) with four replicates were assigned to 20 irrigated plots. Effect of N application rates on cotton lint yield was significant in 2014 (p = 0.0196), but not in 2013. Yield showed a quadratic relationship with leaf N content in irrigated cotton in both 2013 (p = 0.0268) and 2014 (p = 0.0099). Correlation between leaf N and yield of rainfed cotton was not significant in 2013. Leaf N of irrigated cotton in 2014 had significant correlation with fiber length (p = 0.0037), UQL (p = 0.0001), and UHML (p < 0.0001). Yellowness was linearly related with leaf N content. Fiber strength showed a linear relationship with leaf N in 2013 rainfed cotton (p = 0.0495), a quadratic relationship with irrigated cotton in 2013 (p = 0.0231) and 2014 (p = 0.0365). Overuse of nitrogen fertilizer in cotton could result in loss of yield and fiber quality. When the fiber quality from irrigated cotton was compared with rainfed cotton, irrigation increased lint yield by 26% and fiber length by 2%.

Cotton (*Gossypium hirsutum* L.) is the most popular natural fiber for clothing and textile products, accounting for approximately 25% of total world fiber use (USDA, 2017). The U.S. is among the top five cotton producing countries and the largest cotton exporter in the world. Most of the cotton in U.S. is grown in a region known as the Cotton Belt, which includes humid regions in the Mid-South U.S.

Both the yield and fiber quality of cotton are important factors in determining a producer's profit. Producing high-yielding and high-quality cotton requires careful management in every production stage, including field management practices in fertilization and irrigation. Nitrogen (N) nutrient can affect lint yield and fiber properties (Bauer and Roof 2004; Fritschi et al., 2003; Girma et al., 2007). Those effects can vary with other inputs including soil types, water supply, and climatic conditions (Gerik et al., 1998). In general, N and water are two major constraints limiting the yield and quality of cotton. Either under-use or over-use of N fertilizer can create a negative effect on desired growth pattern of cotton plants and cause decrease of the yield and fiber quality (Fernandez et al., 1996; Gerik et al, 1998). Nitrogen deficiency can reduce plant vegetative growth and fruiting, and induce premature senescence resulting in low yield and fiber quality (Gerik et al., 1994). Excess nitrogen can cause excessive vegetative growth, delay maturity, create difficulty in defoliation, increase pest problems, and ultimately reduce the crop yield and fiber quality (Cisneros et al., 2001; Howard et al., 2001; Tewolde and Fernandez, 1997). Much of the research on N effect on cotton yield and fiber quality used N fertilization rate as the independent variable. There have been limited studies on the relationship among the crop yield, quality, and the plant leaf N concentration.

Water stress in cotton plants can limit plant growth and productivity, resulting in reduction of yield (Cull et al., 1981). Pettigrew (2004) studied the effects of moisture deficit stress on cotton lint yield and fiber quality and reported that compared with irrigated plants, dryland plants under water stress reduced lint yield by 25%. Irrigated plants produced more bolls and approximately 2% longer fiber than the dryland plants. Irrigation effects on

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cotton yield and quality with different tillage system were investigated by Balkcom et al. (2006). They found that irrigation improves ginning percentage and increased yield, and fiber quality parameters such as the length, micronaire, and uniformity were affected by the irrigation regimes. Basal et al. (2009) reported a field trail in cotton on the effects of various drip irrigation ratios on the water use efficiency, yield, and fiber quality. Their results showed that seed cotton yields increased as the irrigation levels increased, Fiber quality was influenced significantly by irrigation levels. Fiber length was reduced in response to soil moisture deficits. Morrow and Krieg (1990) reported that increasing N supply at fruiting period increased yield when the water supply was sufficient, and water-use efficiency during post-flower period was increased with N applications. But they did not report the impact of N and water supply on fiber quality. An improved understanding of the interaction of water and nutrient on cotton yield and quality on a long-term environment and field scale would help producers in management of N and water application for maximizing yield and fiber quality and minimizing environmental impact.

Nitrogen uptake by cotton is proportional to the plant's photosynthetic capacity and dry matter accumulation. Prior to squaring stage, cotton plants have a low N requirement. The majority of N is taken up between early square and peak bloom (Fritschi et al., 2004). Normally N deficiency in cotton does not occur before early square even if there is no N fertilizer applied before planting because residual soil N can be sufficient to meet N requirement of young cotton stands. As the season progresses, especially at peak bloom stage, N deficiency will occur in cotton leaf N content if appropriate amount of N has not been supplied. Direct measurement of total N content of most recent, fully expanded cotton leaves in the upper canopy is one of the most reliable methods to assess N status of cotton plants (Gerik et al., 1998). In this study, different N rates were applied in testing plots to generate different leaf N contents. To obtain a wide range of leaf N content for detecting the effect of N nutrient on cotton yield and fiber quality, cotton leaf samples were collected during peak bloom stage and analyzed for leaf N content.

Though typical annual precipitation in Mid-South U.S. is approximately 130 cm, approximately 18% of the precipitation occurs during June to August when crops require a large quantity of water to grow. Furthermore, the precipitation patterns in summer frequently include heavy rainfall events that increase runoff from cropland with only a small amount of rainfall percolated into the soil profile and available for plant use (Earth Gauge, 2017). Uncertainty in the amount and timing of precipitation is a serious risk to crop production in the Mid-South region. Studies demonstrated that supplemental irrigation in this humid region could increase crop yield and reduce production risk (Gwathmey et al., 2011; Pettigrew, 2004). Producers in this region are increasingly reliant on supplemental irrigation to ensure adequate yields. Irrigated lands in the Mid-South U.S. are increasing rapidly in recent years. Reassessment of effects of irrigation and interaction of irrigation with N fertilization on cotton yield and fiber quality is necessary for improving profitability and sustainability of cotton production in the region.

Cotton fiber quality is the physical properties of cotton fiber, which have direct effect on processing performance, yarn quality, and end products in the textile industry. The most important fiber properties include fiber length, length uniformity, strength, color, and fineness. Every bale of cotton produced in the U.S. is classified for quality by the U.S. Department of Agriculture (USDA) classing offices before entering the market (Cotton Inc., 2016). The principal instrumentation systems used for cotton fiber quality measurement are the High Volume Instrument (HVI) for commercial evaluation and the Advanced Fiber Information System (AFIS) (Uster Technologies, Knoxville, TN) often used by textile mills and researchers. Typical cotton fiber characteristics measured by these instruments are described by Peters and Meier (2010).

The objective of this study was to investigate the relationship among N application rates, leaf N content, lint yield, and fiber quality in irrigated and rainfed cotton.

MATERIALS AND METHODS

Experiment Layout. This study was conducted in a cotton field near Stoneville, MS (latitude: 33°26'30.86", longitude: -90°53'26.60"). Predominant soil in the field was silt loam. Slope from the east side of the field to the west was approximately 0.5%. Forty-eight plots in 2013 and 20 plots in 2014 were laid out in this field. Plots were 48.8 m long, 23.2 m wide, and each contained 24 rows with row spacing of 0.97 m. A 7.7-m wide buffer was used between the plots. Among those plots, the same or almost the same amount of N was applied in the same plot since the 2011 season. In 2013, the experiment consisted of two irrigation regimes, irrigated and rainfed. The cotton field was split into two large blocks. One was in the irrigated regime and the other in the rainfed. Six N application rates (0, 39, 67, 101, 135, and 168 kg/ha) were used as treatments in each block. Each treatment had four replicates within one irrigation regime. This resulted in 24 irrigated plots and 24 rainfed plots. One N application rate was assigned to each plot using a completely randomized design in each irrigation region. In 2014, a randomized complete block design (RCBD) was used with two blocks. There were five N treatments (0, 56, 112, 168, and 224 kg/ha) with two replicates in each block resulting in 20 plots in total. Nitrogen treatments were randomly assigned to the plots within a replicate. All plots were irrigated in the 2014 season. Irrigations were conducted using a center-pivot sprinkler irrigation system.

Nutrient and Water Management. Cotton cultivars FM2989GLB2 and FM1944GLB2 were selected in 2013 and 2014, respectively. Seed of both cultivars were provided by Bayer CropScience (Research Triangle Park, NC). The plots were planted on 21 May 2013 and 21 April 2014. Nitrogen fertilizer at the designated rate was applied as a urea-ammonium nitrate solution (N-sol, 32%) to each plot with a side knife drill 31 d after planting (DAP) in 2013 and 57 DAP in 2014. Insects and weeds in the plots were controlled with the generally recommended procedures of the region throughout the growing seasons.

Soil moisture sensors (EC-5 and 5TM, Decagon Devices, Pullman, WA) were installed in soil at depths of 15, 30, and 61 cm. Irrigations were scheduled based on soil moisture content measured by soil moisture sensors during the season. At early growth stage, irrigation was triggered when soil volumetric water content was approximately 0.25 m^3/m^3. After 60 DAP, irrigation was scheduled as the water content decreased to approximately 0.2 m^3/m^3. In 2013, water depth of 16 cm in total was applied to the irrigated plots in five irrigation events on 2 July, 16 July, 7 Aug., 23 Aug., and 26 Aug., respectively. Water depth of 3.2 cm was applied in each irrigation event. Compared with 2013, there was more precipitation in 2014. Therefore, only two irrigation events were scheduled on 1 Aug. and 8 Aug. during the season. Each event applied approximately 2.5 cm depth of water. Irrigation was ended at the stage of first open boll.

Sample Collection and Analysis. Leaf samples were collected at 90 and 100 DAP in 2013 and 2014, respectively. Ten uppermost fully expanded main-stem leaves were taken to make one composite leaf sample. Three composite leaf samples were randomly collected in each plot. Leaf samples were analyzed by the Kjeldahl procedure for N content. The average N content values of the leaf samples from each plot was calculated to represent plant N status in the plot.

In 2013, defoliation was initiated on 21 Oct. The center 16 rows of each plot were machine harvested with a spindle-type picker on 19 Nov. For 2014 season, the plots were defoliated on 1 Sept. and harvested on 1 Oct. with the same procedure as in 2013. Seed cotton harvested from the center 16 rows of each plot was weighted for yield determination. Approximately 38 kg of seed cotton were randomly collected from each plot during harvest for fiber quality analysis.

The seed cotton samples were ginned using the micro-gin at the USDA ARS Cotton Ginning Research Unit (CGRU) in Stoneville, MS (Fig. 1). The ginning sequence included dryer 1, cylinder cleaner, stick machine, dryer 2, cylinder cleaner, extractor feeder gin stand, and saw-type lint cleaner. There was no heat added in the dryers in the ginning process. The lint from each seed cotton sample was weighed and the gin turnout was calculated. Ten subsamples were collected after the lint cleaner from each sample for fiber quality analysis, five of them for testing with AFIS and five for HVI. All lint samples were analyzed in the USDA ARS SRRC (Southern Regional Research Center) in New Orleans, LA. Fiber quality parameters measured with AFIS and HVI tests included micronaire, fiber length, maturity, strength, elongation, color, and short fiber content.

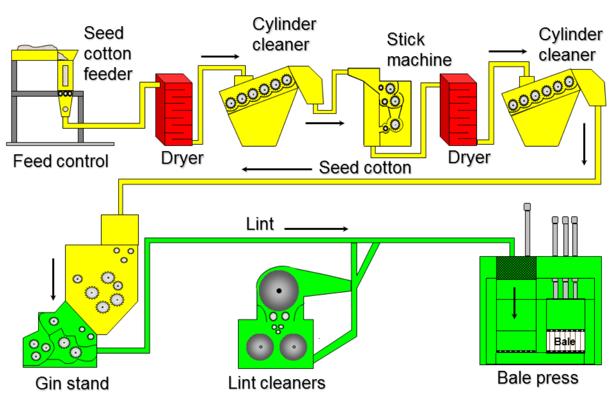

Figure 1. Micro-gin of USDA ARS Cotton Ginning Research Unit at Stoneville, Mississippi.

Data Analysis. An ANOVA was performed to compare the yield among the treatments of N rate applied. Regression analysis was used to find the effect of N application rates on lint cotton yield and fiber quality. Linear, quadratic, and log linear trends were considered and the trend providing the best estimate of the effect of N rate was chosen. The same regression analysis steps were employed with the leaf N content as the independent variable.

RESULTS AND DISCUSSION

Leaf N Content Versus N Application Rate. In 2013, overall plant leaf N content varied from 2.47 to 4.14% with an average of 3.36% in rainfed plots and from 1.72 to 4.37% with an average of 3.53% in irrigated plots. Leaf N content of irrigated plants on average was 5.1% higher than the rainfed. Leaf N had weak correlation with N application rate in rainfed plots (p = 0.947). However, leaf N was closely correlated with the N application rate in irrigated plots ($p < 0.0001$) (Fig. 2). In the 2014 season, all plants were irrigated. The leaf N average was 3.51% in a range from 1.77 to 4.28%. Leaf N in 2014 showed a strong polynomial relationship with N application rate ($p < 0.0001$) (Fig. 3). In terms of its average and variation, leaf N in 2014 was consistent with that of the irrigated plants in 2013. Our results were comparable with those reported by Bauer and Roof (2004). Leaf N content of the irrigated plants was more sensitive to fertilizer application rate than the plants that were rainfed. Both the amount and variation of leaf N content in irrigated plots was greater than that of the rainfed plants. Irrigation could improve plant capability to utilize the applied N fertilizer. Leaf N concentration increase flattened as the N fertilizer rate approached 168 kg/ha in this study.

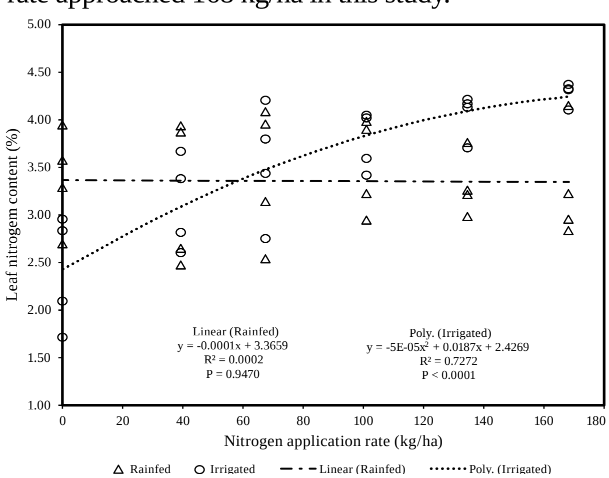

Figure 2. Leaf nitrogen content versus nitrogen fertilizer application rate in 2013.

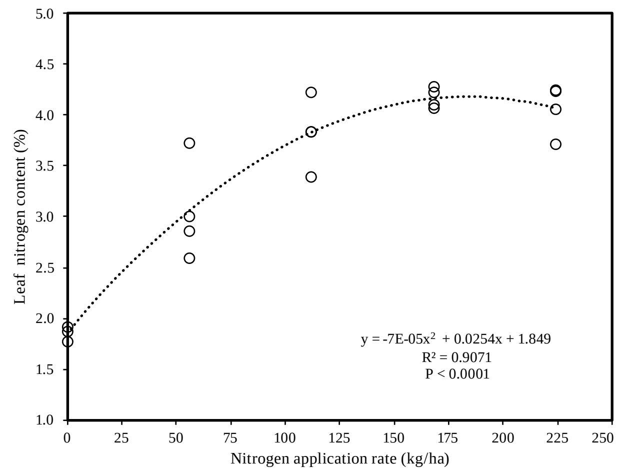

Figure 3. Relationship between leaf nitrogen content and nitrogen fertilizer application rate in 2014 irrigated cotton.

Cotton Yield. Table 1 shows the cotton lint yield in 2013. Yield of irrigated cotton was higher than the rainfed at every N rate. On average, irrigation increased yield by 26%. The ANOVA indicated the N rate had no significant effect on the yield in both the irrigated and rainfed cotton and the yield did not differ between N rates. In the 2014 season, the yield was similar to that of the irrigated cotton in 2013. The highest yield occurred with the N rate of 56 kg/ha. However, the effect of N rate on yield was significant in 2014 (p = 0.0196), and the yield in zero N application treatment was significantly lower than the rest of the treatments (Table 2). Yield showed a second-order polynomial function with N application rate for irrigated cotton during the 2013 and 2014 seasons (Fig. 4). However, the trend of the relationship was not significant for either year (p = 0.2583 in 2013, p = 0.1026 in 2014). Cotton yield increased with N application up to an application rate of approximately 70 kg/ha (Tables 1, 2; Fig. 4). And the yield did not increase with increased N rate beyond that rate in this case. In irrigated cotton, yield had a quadratic relationship with leaf N content in 2013 (p = 0.0268) and in 2014 (p = 0.0099) (Figs. 5, 6). The highest yield was observed at approximately a leaf N content of 3.5%. Yield of the rainfed cotton showed a weak linear correlation with the leaf N content (p = 0.2850) (Fig. 5). A quadratic response of Pima lint yield to N rate was reported by Fritschi et al. (2003). They observed that lint yield decreased from a rate of 168 kg N ha^{-1} to 224 kg N ha^{-1}.

Table 1. Comparison of lint yield with different N application rates in rainfed and irrigated cotton in 2013

N rate (kg/ha)	Obs. No.	Rainfed Yield (kg/ha)		Irrigated Yield (kg/ha)	
		Mean	Std Dev	Mean	Std Dev
0	4	525	138	560	14 7
39	4	449	77	655	104
67	4	490	60	683	116
101	4	459	114	661	164
135	4	565	215	614	98
168	4	502	69	590	107

Table 2. Comparison of lint yield with different N applications in 2014

N rate (kg/ha)	Obs. No.	Yield (kg/ha)	
		Mean[z]	Std Dev
0	3	42a	2
5	4	70b	13
11	4	61b	12
16	4	60b	3
22	4	63b	5

[z] **Means with the same letter are not significantly different at the 0.05 level.**

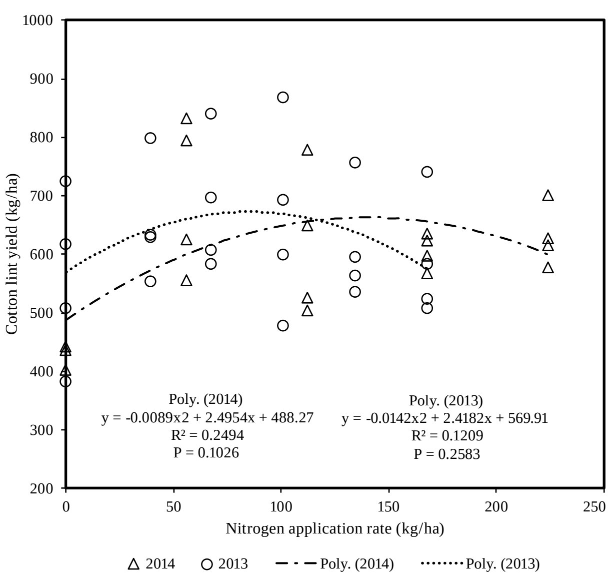

Figure 4. Irrigated cotton lint yield had polynomial relationship with nitrogen application rate.

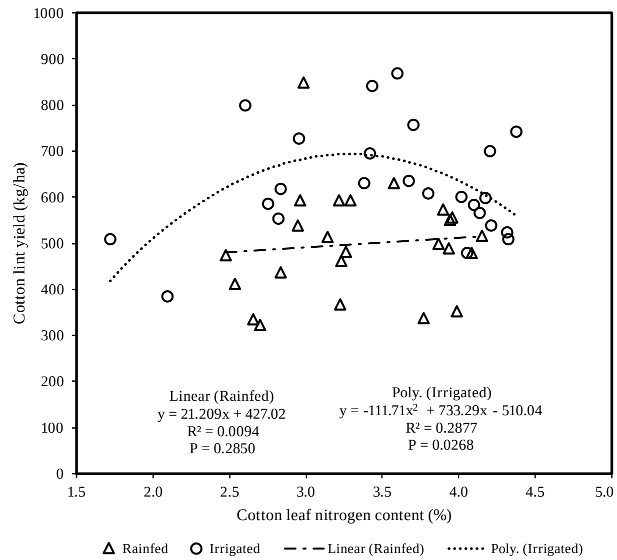

Figure 5. Cotton lint yield versus leaf nitrogen content in 2013 irrigated and rainfed cotton.

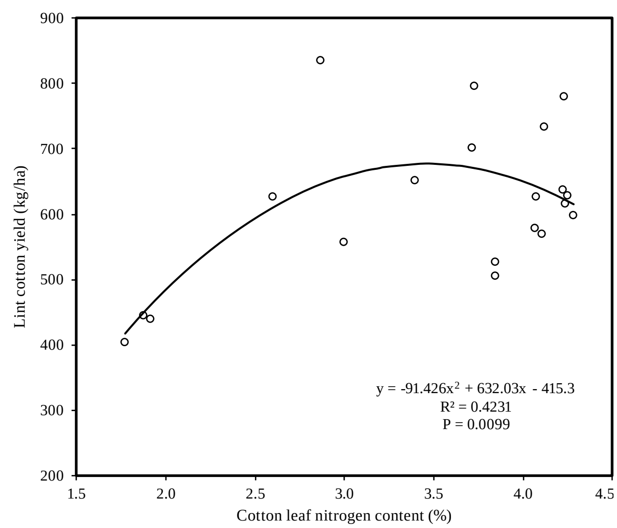

Figure 6. Relationship between cotton lint yield and leaf nitrogen content in 2014 season.

Cotton Fiber Quality. ***AFIS Test.*** In the 2013 season, no significant difference between N application rates was observed in any AFIS properties. Fiber length, upper quartile length (UQL), nep, and fineness (Fine) of the rainfed cotton were significantly affected at 0.05 level by leaf N, but not by N application rate. Irrigation increased fiber length (L[w]) and UQL by 1.9 and 2.5%, respectively. Our result was consistent with that reported by Pettigrew (2004), Basal et al. (2009), and Balkcom et al. (2006). UQL showed a quadratic relationship with the leaf N in irrigated cotton (p = 0.1584) and a negative linear correlation in rainfed cotton (p = 0.0005) (Fig. 7).

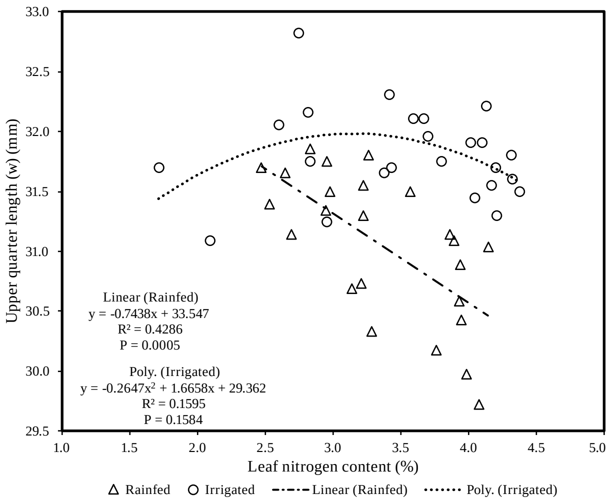

Figure 7. Relationship between AFIS fiber upper quarter length (UQL) and cotton leaf nitrogen content in 2013.

In the 2014 season, no effect of N rate on fiber length was found between N treatments except the treatment with zero N rate. The fiber length with zero N rate was significantly shorter in both L[w] and UQL ($p < 0.05$) than the other application rates. The nep content increased as N rate increased ($r^2 = 0.79$). Fiber length, UQL, and nep content was significantly correlated with N application rate and leaf N ($p < 0.05$). UQL had a quadratic relationship with leaf N ($p = 0.0001$) (Fig. 8), which was consistent with that in 2013 irrigated cotton.

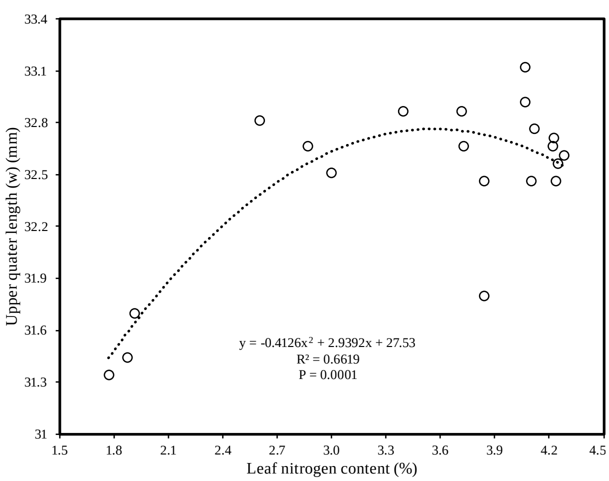

Figure 8. Relationship between AFIS fiber upper quarter length (UQL) and cotton leaf nitrogen content in 2014.

Results indicated that excessive application of N fertilizer had a negative effect on fiber length. The leaf N content associated with the optimal UQL was approximately 3.5% in irrigated cotton of this study. Irrigation reduced short fiber in lint. Short fiber content (SFC[w]) was 6.1% for irrigated cotton, whereas it was 6.4% for rainfed cotton in 2013. The SFC[w] was 8.4% in 2014, which was higher than that in 2013. That could be due to a different cultivar used and different weather conditions.

HVI Test. In the 2013 season, there were no significant effects of N rate on HVI properties except on fiber yellowness (+b) and reflectance (Rd) in irrigated cotton. The yellowness showed a strong positive linear relationship with N rate ($p < 0.0001$), whereas the Rd was negatively correlated with N rate ($p = 0.0016$). In the 2014 season, the same tendency on yellowness and Rd were observed. The yellowness remained a linear relationship with N rate ($p = 0.0014$). However, the correlation between Rd and N rate was not significant ($p = 0.1990$).

In 2014, micronaire with zero N rate was higher than that with rest of the N rates and the micronaire decreased as N rate increased ($p = 0.0007$). Micronaire was significantly correlated with leaf N in 2013 rainfed cotton ($p = 0.0025$) and 2014 irrigated cotton ($p = 0.0006$). However, the micronaire had a weak positive linear relationship with leaf N in 2013 ($r^2 = 0.35$ for rainfed, $r^2 = 0.06$ for irrigated) and a negative linear relationship in 2014 ($r^2 = 0.47$). The rainfed cotton had higher micronaire than the irrigated cotton in 2013. Micronaire is affected by maturity. The irrigated plants coupled with higher leaf N could have more upper bolls, and bolls in the third and fourth sympodial positions would be lower in micronaire.

In 2013, upper half mean length (UHML) showed a linear trend ($p = 0.0063$) with leaf N in rainfed cotton and a quadratic trend ($p = 0.0791$) in irrigated cotton (Fig. 9). In rainfed cotton, UHML decreased as leaf N increased. This result was consistent with that reported by Pettigrew and Zeng (2014). They revealed that N fertilization decreased fiber length 3% in dryland cotton. UHML of irrigated cotton was greater than that of the rainfed. In 2014, fiber UHML, uniformity index (UI), and strength were significantly improved with increasing N rate up to 56 kg/ha; no effect of N rate on those properties was observed with any higher N rates. The effect of leaf N and N rate on UHML was significant ($p < 0.0001$, $p = 0.0006$). UHML had a quadratic relationship with leaf N ($r^2 = 0.78$) (Fig. 10).

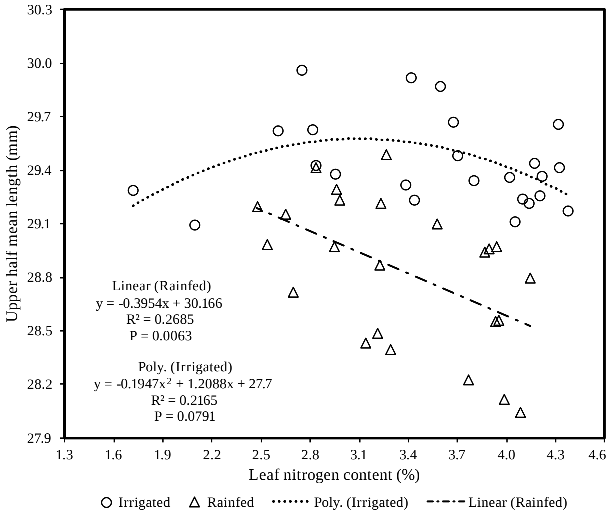

Figure 9. HVI Upper half mean length of fibers versus leaf nitrogen content of irrigated and rainfed cotton in 2013.

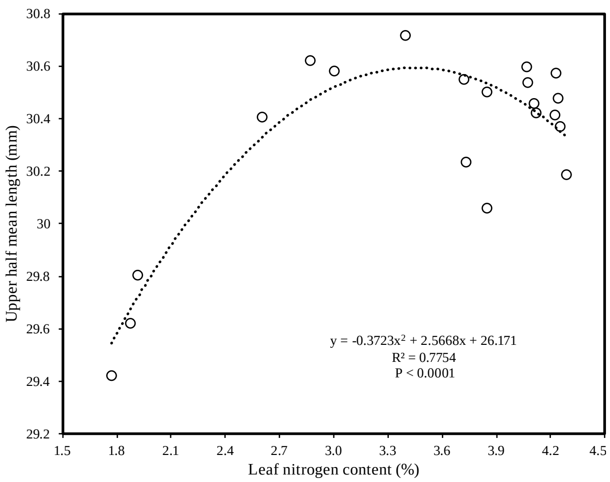

Figure 10. Upper half mean length of fibers versus leaf nitrogen content in 2014 irrigated cotton.

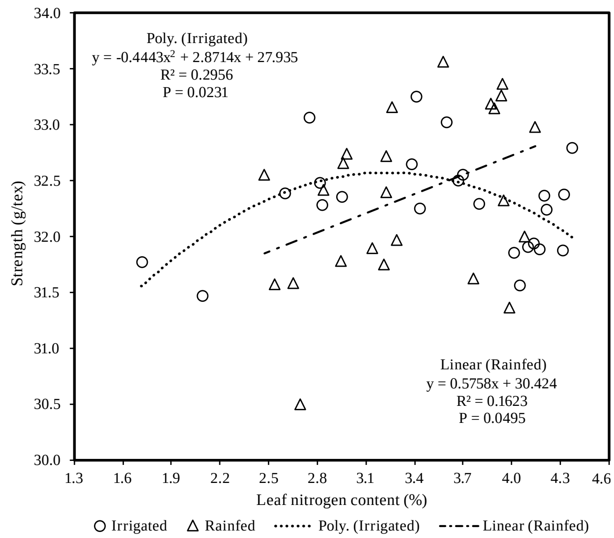

Figure 11. Fiber strength versus leaf nitrogen content of irrigated and rainfed cotton in 2013.

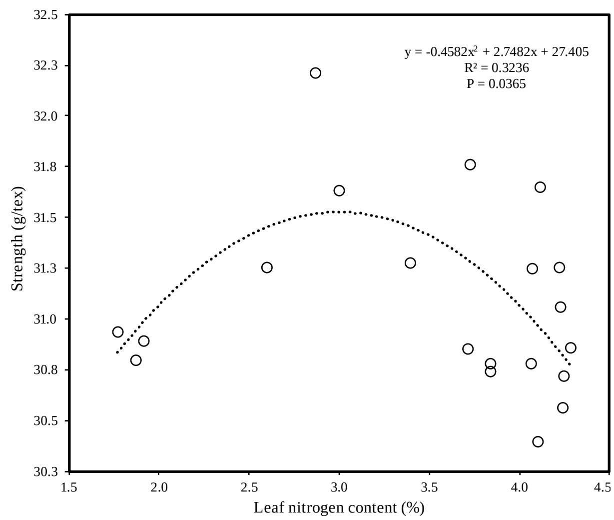

Figure 12. Fiber strength versus leaf nitrogen content in 2014.

Fiber strength was affected significantly ($p < 0.05$) by leaf N content in both seasons. In irrigated cotton, fiber strength had quadratic correlation with leaf N (Figs. 11, 12). However, the fiber strength showed a linear relationship with leaf N in the rainfed cotton (Fig. 11). A significant correlation between leaf N and Rd was observed in 2013. Rd decreased as leaf N increased ($r^2 = 0.68$ for rainfed, $r^2 = 0.40$ for irrigated). The same trend was found in 2014. Effect of leaf N on +b was significant in 2013 and 2014 ($p \leq 0.0002$). Figures 13 and 14 illustrate that +b had a close linear relationship with leaf N content in irrigated and rainfed cotton. Low Rd coupled with +b could result in reduced market price of the cotton fiber. Gin turnout rate of irrigated cotton had a negative linear relationship with leaf N content ($r^2 = 0.51$).

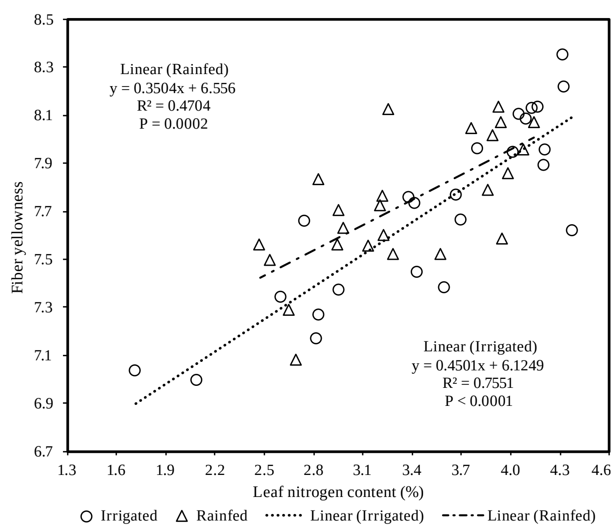

Figure 13. Fiber yellowness versus leaf nitrogen content of irrigated and rainfed cotton in 2013.

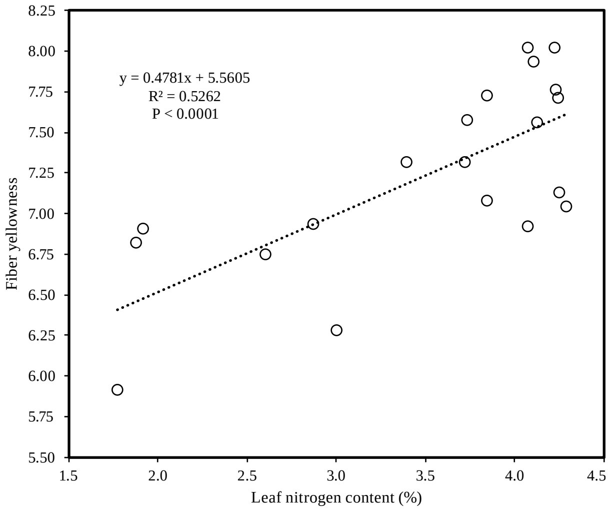

Figure 14. Fiber yellowness versus leaf nitrogen content in 2014.

Rosolem and Mellis (2010) reported N leaf content increased with N application rate, and yield was significantly correlated with leaf N contents 51, 58, and 65 d after emergence (DAE), or 86 DAE in full blooming stage. These results were consistent with our observations. Read et al. (2006) demonstrated that N-deficient cotton had low fiber length. Bauer and Roof (2004) observed cotton grown with zero N application rate had lower fiber length than cotton grown with the rate of 78 or 112 kg N ha^{-1}. Our results in fiber length were consistent with Read et al. (2006) and Bauer and Roof (2004). In addition, Bauer and Roof (2004) documented lint yield and fiber strength had a quadratic relationship with the amount of total N (fertilizer N plus N in cover crop), and +b in the cotton grown without N fertilizer. Pettigrew and Zeng (2014) reported a consistent effect of N on +b. They found that the fiber from plots that received 112 kg N ha^{-1} fertilizer was 5% yellower than the fiber from plots without N fertilization. The same trends in fiber strength and yellowness were observed in our study. However, our results in micronaire differed from that reported by Bauer and Roof (2004). Their result showed a quadratic relation between micronaire and total N. We observed a positive linear relation between micronaire and leaf N in one year and a negative linear relationship in the other year. Micronaire measures the surface area of lint and is an indication of fiber fineness and maturity. During fiber developmental stages in the cotton plant, many factors including weather conditions, nutrient and water stresses, defoliant application time, and cultivar are able to impact micronaire (Hake et al., 1990). Therefore, it was not surprising that the N management effects on micronaire reported here were inconsistent with those reported by others (Basal et al., 2009; Fritschi et al., 2003).

In summary, we found that leaf N content increased as N rate increased in irrigated plots, but not in rainfed plots. Irrigation improved cotton yield, fiber length, and use efficiency of N fertilizer. Fiber yellowness increased with leaf N increase in irrigated and rainfed cotton. With the increase of leaf N, fiber length increased in irrigated cotton, and decreased in rainfed cotton. Use of leaf N as a variable could help observe a continuous response of the yield and fiber property to N status of the plant, which provides a precision tendency between the related variables.

CONCLUSIONS

Field study on effects of N fertilizer application rates on cotton leaf N content, cotton yield, and fiber quality were conducted with irrigated and rainfed cotton over two years. The leaf N showed a polynomial relationship with N application rate ($p < 0.0001$) in irrigated cotton. A quadratic relationship between cotton yield and N fertilizer application rate was observed. As yield reached its plateau, over-use of N fertilizer resulted in negative effects on the yield and fiber quality. Supplemental irrigation increased lint yield by 26% and fiber length by 2%. Irrigation could improve plant capability in utilizing the applied N fertilizer. Cotton leaf N content had an effect on fiber quality including fiber length, micronaire, strength, and color. UHML and fiber strength showed a quadratic relationship with leaf N content in irrigated cotton and a linear relationship in the rainfed cotton. Fiber reflectance decreased and yellowness increased as leaf N content increased. Nitrogen nutrient for cotton needs to be carefully managed with irrigation. In addition to increasing the production cost, excessive application of N fertilizer in cotton would reduce the lint yield and possibly degrade some fiber properties.

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DISCLAIMER

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