The *Journal of Cotton Science 11:12–19 (2007)*
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AGRONOMY AND SOILS

Cotton Lint Yield and Quality As Affected by Applications of N, P, and K Fertilizers

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ABSTRACT

Nitrogen (N), phosphorus (P), and potassium (K) fertilizer use in cotton production is important. Data from a long-term experiment initiated in 1972 were used to evaluate effects of N, P, and K fertilization on lint yield and lint quality of Upland cotton in Oklahoma. The experimental design was a randomized complete block with four replications. Eleven treatments containing different rates of N-P-K were evaluated for each of three cultivars (Paymaster 145, Paymaster HS26 and Paymaster 2326 BG/RR). Analysis of variance (ANOVA) was carried out initially using general linear models (GLM) procedure in SAS. Using this preliminary analysis, a quadratic plateau model for lint yield against N rates was evaluated for each cultivar using nonlinear (NLIN) procedure in SAS. Application of all three nutrients had some effect on lint yield, although most of the response was attributed to N (all cultivars) and to some extent P (Paymaster 2326 BG/RR and Paymaster HS26). The critical N rate for Paymaster 145, Paymaster HS26, and Paymaster 2326 BG/RR was 45, 45, and 67 kg N ha^{-1} with a corresponding plateau lint yield of 734, 1156, and 1468 kg ha^{-1}, respectively. The results for fiber length indicate that K fertilization is the key to long fibers, while N rates greater than 90 kg ha^{-1} significantly reduce lint quality variables.

The availability of N, P, K, and water are the major constraints in cotton (*Gossypium hirsutum* L.) production in most cotton producing environments (Morrow and Krieg, 1990). Nitrogen is generally considered a yield limiting factor in both dryland and irrigated cotton production systems that focus on optimizing lint yield and avoiding excessive applications that reduce quality (Hutmacher et al., 2004).

Mullins and Burmester (1990) and Unruh and Silvertooth (1996) reported that the cotton crop contains about 22.7-25.0 kg N bale^{-1}. Deficiency of N in cotton can reduce both vegetative and reproductive growth and induce premature senescence leading to potential yield loss (Gerik et al., 1994). Alternatively, excess N promotes vegetative development often at the expense of reproductive development, especially at bloom or at early boll fill (Mullins and Burmester, 1990; Howard et al., 2001; Tewolde and Fernandez, 1997). Excess N can indirectly affect lint yield by enhancing aphid (*Aphis gossypii* Glover) infestation, which can complicate cotton defoliation (Cisneros and Godfrey, 2001) and can cause sticky cotton problems because of aphid honeydew secretions (University of Arizona, 1999; Slosser et al., 1999).

In a 3-yr experiment, lint yield increased linearly with N fertility levels each year, attaining a maximum yield of 1842 kg ha^{-1} at 224 kg ha^{-1} N (Fritschi et al., 2003). Increased N decreased gin turnout at one location, but it was not significant at the other sites. Yield advantages because of optimal N application have been attributed to larger bolls at a greater number of fruiting sites (Boquet and Breitenbeck, 2000; Boquet et al., 1994; McConnell et al., 1998; Moore, 1999). Boquet (2005) reported that increasing N from 90 to 157 kg ha^{-1} did not result in increased lint yield in irrigated or rain-fed cotton.

One aspect of N nutrition in cotton is its effect on lint quality. Fritschi et al. (2003) reported a positive linear relationship between fiber strength and N fertility level from a 3-yr study. Boman and Westerman (1994) showed no relationship between fiber strength and N rate. Bauer and Roof (2004) observed lower lint quality, including fiber length, length uniformity, and fiber strength, in plots that did not receive N fertilization.

Several factors, including soil type, affect cotton response to P. The critical level of P is a function of actual concentration of the labile pool that in turn

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determines the available P at a given time during the growth of cotton (Crozier et al., 2004). Several variables, including early P accumulation, biomass, and lint yields, positively responded to P fertilization in calcareous soils (Bronson et al., 2003). Reiter and Kreig (2000) reported some positive and notable P effects on lint fiber quality factors, although both lint yield and lint quality were driven more by moisture availability than by P.

Potassium influenced cotton lint yield by affecting late season growth. Potassium fertilization increased cotton yield by 9% in 2 yr of a 3-yr study (Pettigrew, 2003). In that experiment, K showed little effect on lint quality. The positive effect of K on lint quality characteristics have been documented in several reports (Bennet et al., 1965; Pettigrew, 1999; Pettigrew and Meredith, 1997). According to these authors, the effect of K on fiber quality characteristics tended to be more critical than its effect on lint yield, especially when deficiency is expected in a field. Growth rate and maturity of cultivars were reported to be important factors associated with K and its effect on fiber quality (Pettigrew et al., 1996; Pettigrew, 1999).

Early maturing genotypes of cotton are more susceptible to K deficiency than late maturing cultivars (Pettigrew, 1999). Since current cotton cultivar improvement strategies involve hastening maturity, assessment of K nutrition in cotton production will remain significant. Early maturing cultivars grown under limited K will become deficient in the nutrient, and force the plants to terminate reproductive growth and subsequently reduce lint yield (Pettigrew et al., 1996) to some extent and quality to a larger extent. Pettigrew et al. (2005) reported that the application of 112 kg ha^{-1} K did not increase lint yield in eight out of nine genotypes but had a positive effect on lint quality. According to Minton and Ebelhar (1991), K deficiency is also known to affect lint yield and quality indirectly through exacerbating root-knot nematode [*Meloidogyne incognita* (Kofoid & White) Chitwood] injury.

The benefit of N and P fertilizer nutrients largely depends on the input responsiveness of cotton cultivars (Nichols et al., 2004), as shown previously with K. According to Meredith et al. (1997), the responsiveness of cotton cultivars to N have been developed over time focusing on early maturity and more determinate growth habits. Most cotton cultivars under production today are more responsive than older cultivars as a result of improved agronomic practices, breeding, molecular genetics and transgenic traits, and boll weevil (*Anthonomous grandis* Boheman) eradication in most cotton producing regions of the USA. The objective of this research was to evaluate effects of N, P, and K fertilization on Upland cotton lint yield and lint quality in Oklahoma.

MATERIALS AND METHODS

A long-term experiment was established in 1972 on the western side of the Irrigation Research Station at Altus, Oklahoma, on a soil that had previously been in continuous cotton under conventional tillage since 1964. Data from 1989 to 2004 was used to evaluate effects of N, P, and K fertilization on cotton lint yield and quality. The soil is classified as a Tillman clay loam (fine, mixed, superactive, thermic vertic Paleustolls). Soil NH_4-N, NO_3-N, P, K, total N, organic carbon, and pH in the top 15 cm in the check plot (sampled in 1988) were 5.11, 4.37, 64.8, 677.3 mg kg^{-1}, 750 g kg^{-1}, 0.85% and 7.4, respectively. Ammonium-N and NO_3-N were determined using a continuous flow spectrophotometer (Lachat Instruments, 1992); P and K using Mehlich-3 (Mehlich, 1984); organic carbon and total N using a Carlo-Erba NA-1500 dry combustion analyzer (Milan, Italy); pH as 1:1 soil:water paste.

The plots were six rows wide (1.02-m row spacing) by 18.3 m long. The experimental design was a randomized complete block with four replications. Eleven treatments containing different rates of N-P-K were evaluated. The treatments were as follows: a check (0-0-0 kg ha^{-1} N-P-K), six N rates (0, 45, 90, 135, 180, and 225 kg ha^{-1} at a fixed rate of 20-75 kg ha^{-1} P-K), three P rates (0, 39, and 59 kg ha^{-1} at a fixed rate of 135-75 kg ha^{-1} N-K), and an additional treatment of 135-20-0 kg ha^{-1} N-P-K. The N, P, and K fertilizer sources used were ammonium nitrate (34-0-0 N-P-K), triple super phosphate (0-20-0 N-P-K), and potassium chloride (0-0-51 N-P-K), respectively. All treatments were broadcast on the surface and incorporated prior to planting, and irrigation was applied as needed from the Lugert Altus Irrigation District with amounts varying from year to year. Since the irrigation water was furrow applied, the amount applied per irrigation was approximately 50 to 60 mm. Cultural practices and other information pertaining to the experiment are summarized in Table 1. The cotton cultivars were Paymaster 145 (Delta Pine and Land Co.; Scott, MS) from 1989 to 1994, Paymaster

HS26 (Delta Pine and Land Co.) from 1995 to 2000, and Paymaster 2326 BG/RR (Delta Pine and Land Co.) from 2001 to 2004. Recommended rates of herbicides, fungicides, and insecticides were applied each year. Also, defoliant was applied each year to facilitate harvesting. At maturity, the middle two rows of each plot (15.2 m long) were mechanically harvested with a commercial cotton striper. Grab samples were collected from the harvested material in each plot and ginned on small ginning equipment in order to approximate lint turn out and ginning percentage.

Table 1. Planting, harvesting, and fertilization dates and experimental approach for the long-term cotton experiment

Cultivar	1989-1994	1995-2000	2001-2004
	Paymaster 145	Paymaster HS26	Paymaster 2326 BG/RR
Fertilization date	Mar. - May	May	Mar. - Apr.
Planting dates	May	May	May
Ave. seed rate (kg/ha)	21	19	18
Ave. frequency of furrow irrigation	3	4	5
Harvest date	Oct. - Mar.	Oct. - Nov.	Oct. – Nov.

Preliminary analysis of data from 1989 to 2004 showed that yield was different for the different cultivars used in the study. To overcome this confounding problem and to address the stated objectives, yearly data was grouped by cultivar (Table 2). Furthermore, data from 1995, when lack of moisture at planting and hail damage made treatment comparisons difficult, were removed from analysis.

Initially, analysis of variance (ANOVA) was carried out using general linear models (GLM) in SAS (version 8.1; SAS Institute; Cary, NC) to assess the effect of N, P, K, and two-way interactions on lint yield. Using the significant components from this model, a more practical model was developed for N effect. Nitrogen rate was evaluated by fitting a quadratic plateau model (Nelson et al., 1985) for each cultivar using non-linear regression (NLIN) procedure in SAS. The Nelson et al. (1985) model was

$$Y = \beta_0 + \beta_1 + \beta_2 X^2 \qquad \text{if } X < X_0$$
$$Y = p \qquad \text{if } X > X_0$$

where Y is lint yield (kg ha^{-1}), β_0 is intercept (yield when X = 0); β_1 and β_2 are coefficients of the linear and quadratic phases of the model, respectively; X is N level (kg ha^{-1}); X_0 denotes the critical N level (kg ha^{-1}) at which maximum lint yield is achieved (p).

Table 2. Treatment means and results from analysis of variance for main and two-way interaction effects for each cultivar

N-P-K	Lint yield (kg ha^{-1})		
	Paymaster 145 (89-94)	Paymaster HS26 (95-00)	PM2326 BG/RR (01-04)
0-0-0	568	758	681
0-20-75	584	798	757
45-20-75	735	1169	1240
90-20-75	753	1164	1467
135-20-75	758	1178	1514
180-20-75	725	1159	1478
225-20-75	700	1112	1412
135-0-75	728	1121	1315
135-39-75	759	1212	1574
135-59-75	742	1155	1571
135-20-0	743	1166	1498
Average	709	1090	1319
SED [y]	117	73	63
	Analysis of variance[z]		
N rate	**	***	***
P rate	ns	*	*
N x P	ns	ns	ns
K rate	ns	ns	ns
N x K	ns	ns	ns
P x K	ns	ns	ns
Model R^2	0.15	0.45	0.86

[y] Standard error of the difference of two means.

[z] Source of variation denoted with *, **, and *** are significant at $P \leq 0.05$, 0.01, and 0.001, respectively.

Lint samples were sent to the International Textile Center, Texas Tech University, Lubbock, Texas, for cotton lint quality analysis for Paymaster 145 (1989 to 1994), Paymaster HS26 (1998 to 2000), and Paymaster 2326 BG/RR (2001 to 2003). Lint quality data for 1995 to 1997 was not available. The High Volume Instrument (HVI) system was used to determine lint quality. Variables measured were fiber length (cm), length uniformity (%), strength (cN tex^{-1}), micronaire, and color. Definition of the different fiber quality characteristics and instrument procedures, as well as scales of measurement can be consulted in the literature (USDA-AMS, 2001; USDA-AMS, 2005). Statistical data analysis on fiber quality data was also performed using the combination of SAS procedures indicated above.

RESULTS AND DISCUSSION

Lint yield. Mean lint yields for different cultivars are presented in Table 2. There was a response to fertilization in lint yield for the cultivars. The older cultivar (Paymaster 145) had lower lint yield and responded poorly to fertilizer application (659 kg ha^{-1} lint on average). Paymaster HS26 and Paymaster 2326 BG/RR (a "stacked gene", modern transgenic stripper cultivar with both Bt insect resistance and glyphosate tolerance) were superior (1205 kg ha^{-1} lint on average) to Paymaster 145 in yield. These cultivars may be more responsive to fertilizer partly because the state-wide cotton boll weevil eradication program that has been in effect since 1995.

All cultivars attained maximum lint yield with application of 135-39-75 kg ha^{-1} N-P-K (Table 2). Application of N had a significant effect on lint yield for all three cultivars. Additionally, application of P had a significant effect on lint yield for Paymaster HS26 and Paymaster 2326 BG/RR. Potassium fertilization and all two-way interactions did not affect lint yield for all cultivars (Table 2). The inclusion of these factors resulted in relatively high coefficient of determination (R^2) for Paymaster HS26 (0.86) and Paymaster 2326 BG/RR (0.45). The ability of the model to account for variability for Paymaster 145 (0.15) was poor. The results indicate that lint yield for Paymaster HS26 and Paymaster 2326 BG/RR was mostly affected by N and P, while N was the only nutrient that significantly affected lint yield of Paymaster 145. Application of K might not be necessary from a lint yield perspective, unlike previous studies that recommended 112 kg ha^{-1} K (e.g. Pettigrew, 1999). This is presumably because of the high inherent soil K at the experimental site. Soil samples collected in 1988 averaged 677 mg kg^{-1} of soil K in the plot that did not receive K fertilizer since the start of the experiment.

Response of lint yield to applied N follows a diminishing return trend. The quadratic plateau model for lint yield against N rates showed that the model accounted for 3, 32, and 75% of lint yield variability for Paymaster 145, Paymaster HS26, and Paymaster 2326 BG/RR, respectively (Table 3). For Paymaster 145, a poor relationship was observed between N rates and lint yield. This was consistent with the results of ANOVA for this cultivar. The critical N rate (X_0) for Paymaster 145, Paymaster HS26, and Paymaster 2326 BG/RR was 45, 45, and 67 kg ha^{-1} N, respectively, with a corresponding plateau (p) lint yield of 734, 1156 and 1468 kg ha^{-1}, respectively. These critical N rates are based on the N rates used in this study and did not account for N supplied by the environment. Although cotton requires 25-27 kg ha^{-1} N per bale to attain maximum yield, the crop apparently obtained the additional unaccounted N from atmospheric deposition (about 22 kg ha^{-1} N) and mineralization (34-56 kg ha^{-1} N) (Cowling et al., 2001; Hons et al., 2001). For Paymaster 2326 BG/RR, the data shows that 67 kg ha^{-1} N can support 3 bales of lint. The lint yield of the check (no N fertilizer, i.e. the intercept β_0) for this cultivar was 757 kg ha^{-1}. This yield is the result of residual N available from previous year, atmospheric deposition, and mineralization. For this cultivar the residual N, atmospheric deposition, and mineralization supplied approximately up to 66 kg ha^{-1} N.

Table 3. Parameter estimates of N versus predicted lint yield using a quadratic plateau model for each cultivar

Parameter[y]	Paymaster 145 (89-94)	Paymaster HS26 (95-00)	Paymaster 2326 BG/RR (01-04)
B_0	584	798	757
β_1	4.01	13.1	11.0
β_2	-0.015	-0.113	-0.006
X_0	45	45	67
p	734	1156	1468
R^2	0.03	0.32	0.75
Probability[z]	ns	*	**

[y]B_0 = intercept (yield when X=0); β_1 and β_2 =coefficients of the linear and quadratic phases of the model, respectively; X_0 = the critical N level (kg ha^{-1}) at which maximum lint yield is achieved (p).

[z]Values denoted by * and ** are significant at $P \leq 0.05$, and 0.01, respectively.

Fiber quality. Mean fiber quality data is presented in Table 4. Average fiber length obtained in this study was slightly lower than the average for the Western cotton growing regions that includes Oklahoma (USDA-AMS, 2005), and micronaire was higher than the region's average. Average length for this region is 2.74 cm, and the average obtained in this study was 2.58, 2.63, and 2.69 cm, for Paymaster 145, Paymaster HS26, and Paymaster 2326 BG/RR, respectively. The average length obtained in this study and the one obtained for the region are both categorized as medium length. Micronaire for the region is 3.9 (fine), and the average for Paymaster 145, Paymaster HS26, and Paymaster 2326 BG/RR was 4.1, 5.06, and 5.23, respectively. Micronaire of Paymaster 145 would be considered fine, and micronaire for the other cultivars would be coarse. The difference in these fiber quality characteristics from region to region is presumably related to cultivar differences and to differences in the performance of the same cultivars because of weather and soil-related factors. Bradow et al. (1997) and Reddy et al. (1999) found that weather factors that affect carbon assimilation, such as temperature, influence micronaire. Reddy et al. (1999) showed that micronaire increased linearly with the increase in temperature up to 26 °C but decreased at 32 °C.

Fiber length uniformity and strength were higher for Paymaster 145 and Paymaster HS26 than the Western region average. Fiber length uniformity for the region was 81% (medium), and uniformity was 83% for Paymaster 145 and 84% for Paymaster HS26 and Paymaster 2326 BG/RR. Fiber uniformity index for all cultivars are in the 'high' category. Similarly, fiber strength was 28.4 cN tex^{-1} (base) for the region and was 28.9 and 29.6 cN tex^{-1} (strong category) for Paymaster HS26 and Paymaster 2326 BG/RR, respectively.

Fiber quality characteristics were relatively different for the three cultivars. Fiber length, length uniformity, and strength were all higher for Paymaster 2326 BG/RR (Table 4). Segarra and Gannaway (1994) established that micronaire and strength are to some extent a function of cultivar. Treatments effects on length and strength were significant for Paymaster HS26 and Paymaster 2326 BG/RR (Table 4).

Separate analysis of the effect of different N rates (at a fixed 20 kg ha^{-1} P and 75 kg ha^{-1} K) revealed that length decreases with N rate for Paymaster 2326 BG/RR and Paymaster HS26. Fiber length uniformity and micronaire did not decrease with increasing N rate for both cultivars (Fig. 1 and 2). Fritschi et al. (2003) reported a positive linear relationship between fiber strength and N fertility level over 3 yr. Boman and Westerman (1994) documented the absence of any relationship between fiber strength and N rates. The decrease in lint fiber micronaire with N rate might be

Table 4. Effect of N-P-K fertilizers on mean fiber length, length uniformity (LU), strength, and micronaire measured using High Volume Instrument (HVI) for Paymaster 145 (1989-1994 average), Paymaster HS26 (1998-2000 average), and Paymaster 2326 BG/RR (2001-2004 average)

N-P-K (kg ha^{-1})	Paymaster 145			Paymaster HS26				Paymaster 2326 BG/RR			
	Length (cm)	LU (%)	Micronaire	Length (cm)	LU (%)	Strength (cN tex^{-1})	Micronaire	Length (cm)	LU (%)	Strength (cN tex^{-1})	Micronaire
0-0-0	2.57	83	4.1	2.62	83	28.4	5.0	2.68	84	29.4	5.2
0-20-75	2.57	83	4.0	2.65	84	29.6	5.1	2.73	84	30.4	5.3
45-20-75	2.59	82	4.1	2.64	84	29.5	5.1	2.71	84	30.0	5.3
90-20-75	2.61	84	4.1	2.64	84	29.1	5.1	2.71	84	29.7	5.3
135-20-75	2.56	83	4.2	2.64	84	29.2	5.1	2.70	84	29.7	5.3
180-20-75	2.57	82	4.1	2.64	83	29.0	5.1	2.70	84	29.7	5.2
225-20-75	2.57	82	4.2	2.64	83	28.9	5.0	2.70	84	29.5	5.2
135-0-75	2.59	83	4.2	2.63	83	28.8	5.0	2.68	84	29.4	5.2
135-39-75	2.60	83	4.2	2.63	83	28.7	5.0	2.68	84	29.4	5.2
135-59-75	2.54	82	4.2	2.63	83	28.6	5.0	2.67	84	29.3	5.2
135-20-0	2.57	83	4.2	2.61	83	28.1	4.9	2.67	84	28.9	5.2
Average	2.58	83	4.1	2.63	83	28.9	5.1	2.69	84	29.6	5.2
SED[y]	0.10	0.03	0.45	0.10	0.01	0.36	0.62	0.10	0.15	0.36	0.55
	Analysis of variance[z]										
N rate	ns	ns	ns	ns	ns	*	ns	ns	ns	*	ns
P rate	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
K rate	ns	ns	ns	*	ns	ns	ns	*	ns	ns	ns

[z] Standard error of the difference of two means.

[y] Variables denoted with *, **, and *** are significant at $P \leq 0.05$, 0.01, and 0.001, respectively.

good, since more fine fiber is a desired trait. The results suggest that the soil N released from both inorganic and organic pool was sufficient to maintain good fiber quality. This is true given that plots were fertilized continuously with the same rate year after year. Likewise, for the three P rates (at fixed 135 kg ha^{-1} N and 75 kg ha^{-1} K rates), all quality characteristics were higher for Paymaster 2326 BG/RR. Increase in P rate from 39 to 59 kg ha^{-1} did not result in considerable reduction in measured lint quality variables for Paymaster HS26 and Paymaster 2326 BG/RR (Table 4). This shows that the high P rate, unlike N, had no negative effect on fiber quality.

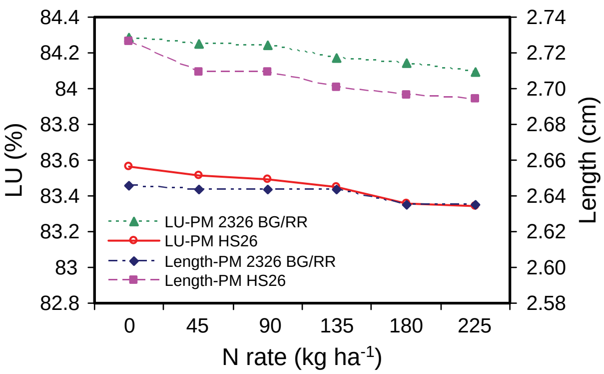

Figure 1. Effect of N rates on fiber length uniformity (LU) and fiber length for Paymaster 2326 BG/RR and Paymaster HS26.

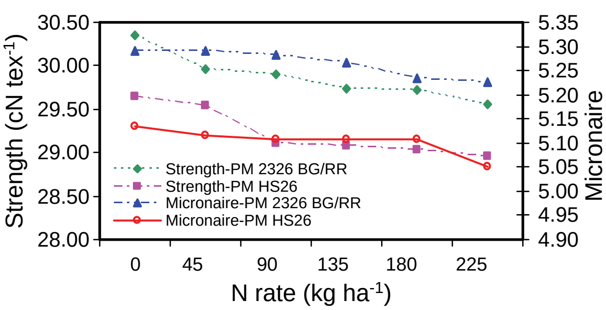

Figure 2. Effect of N rates on fiber strength and micronaire for Paymaster HS26 and Paymaster 2326 BG/RR.

Table 4 also showed an interesting result with respect to K fertilization. The 135-20-0 kg ha^{-1} N-P-K combination was significantly lower in length for Paymaster HS26 and Paymaster 2326 BG/RR than any of the fertilizer combinations containing K, implying the critical role of K in improving fiber length. Length uniformity, however, was not significantly different among the aforementioned fertilizer combinations for both cultivars.

The results from all quality characteristics suggest that K fertilization is a key to better quality, while N rates (greater than 90 kg ha^{-1}) slightly reduce lint quality in Upland cotton (except for micronaire which was improved with presence of moderate to high rates of N in this study at this location with the planted cultivars). These results were generally consistent with previous reports that showed the benefits of K fertilization on lint quality (Pettigrew, 1999; Bennet et al., 1965; Cassman et al., 1990).

The results of this study show that as old cultivars were replaced with the new transgenic cultivars, and as boll weevil pressure was removed, yield potential has changed, which obviously has driven increases in nutrient uptake, especially N. This means new nutrient management practices need to be developed for sustainable cotton production. The fiber quality results also show that the earlier cultivar had short staple and low strength. The data presented here is a resource for planning research in cotton producing areas of Oklahoma and elsewhere.

ACKNOWLEDGEMENT

Contribution from the Oklahoma Experiment Station.

DISCLAIMER

Mention of a cultivar or trademark of any sort does not imply approval for recommendation of the product.

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