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# ECONOMICS

## Influence of Row Spacing, Herbicide Technology, and Tillage on Fiber Quality and Economic Returns

Leah M. Duzy*, Kipling S. Balkcom, and Andrew J. Price

### ABSTRACT

**Agricultural producers are faced with a range of conditions that influence their profitability, from weather variability to weed, insect, and disease pressure. Adoption of new production methods to address these conditions can produce higher or lower yields, as well as differing cotton (*Gossypium hirsutum* L.) fiber quality. The objective of this study was to evaluate the effect of row spacing, herbicide technology, and tillage on fiber quality attributes, quality price difference, ginning percentage, and net returns above variable treatment costs (NR) using data from a field experiment conducted in Alabama from 2004 to 2006. Treatments included nontransgenic, glyphosate-tolerant, and glufosinate-tolerant cotton varieties; conservation tillage and conventional tillage; and standard row (102-cm) and narrow row (38-cm) spacing. Ordered multinomial mixed logit models were used to evaluate fiber quality attributes, quality price difference, and ginning percentage, and a linear mixed model was use to evaluate NR. Fiber quality attributes were most commonly impacted by variety and tillage. Across all fiber quality attributes, nontransgenic and glufosinate-tolerant varieties had a higher probability of producing premium cotton than the glyphosate-tolerant variety due to premiums from micronaire, strength, and uniformity values. Conservation tillage systems had a higher probability of higher values for color grade, staple, and uniformity. Glyphosate-tolerant cotton and cotton grown in a conventional tillage system were more likely to have higher ginning percentages. Spacing and variety were influential in determining NR. These results indicate the importance of considering, not only seed cotton yield, but also fiber quality and ginning percentage when making production decisions.**

In 1970, cotton (*Gossypium hirsutum* L.) production encompassed approximately 229,000 ha in Alabama with an average cotton lint yield of 508 kg ha$^{-1}$. Forty-five years later, the environment for cotton production is different. In 2014, 142,000 ha of upland cotton were planted in Alabama, down approximately 24% from the most recent high of 186,000 ha in 2011 that was 43,000 fewer hectares than were planted in 1970 (USDA-NASS, 2015). Since 2011, when the high price of cotton in early spring drove the large increase in planted hectares in Alabama and across the U.S., cotton prices have declined as has the area of cotton planted. In 2014, average yields in Alabama increased to 1,020 kg ha$^{-1}$ but were highly variable throughout the state, depending heavily on production decisions and adequate rainfall (USDA-NASS, 2015). Cotton producers are dependent on the latest production technology to continue to increase production, improve cotton quality, and maximize profits.

Agricultural producers are faced with a range of conditions that influence their profitability, from weather variability to weed, insect, and disease pressure. Certain conditions can be addressed with technology and production methods (e.g., seed genetics and pesticide regimens); however, adoption of new production methods can produce higher or lower yields, as well as differing qualities of cotton. Agricultural research is necessary to assist producers in adoption of appropriate new technology and production methods for their operation. If a given production system does not maximize profits, few agricultural producers will adopt such systems.

Narrow-row cotton production combined with a conservation tillage system can potentially improve productivity and increase profits. When narrow-row cotton was first introduced, one of the main barriers to adoption was the ability to control weeds within the growing season beyond soil-applied herbicide options. The advent of various transgenic cultivars with herbicide-resistant traits provided weed control opportunities for viable narrow-row cotton in conservation tillage systems (Vories and Glover, 2006; Wilson et al., 2007). Scientists in agronomy, weed science, and economics have published research results on the impact

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L.M. Duzy*, K.S. Balkcom, and A.J. Price, USDA-ARS, NSDL, 411 South Donahue Dr., Auburn, AL 36832
*Corresponding author: leah.duzy@ars.usda.gov

of adopting these production methods on yields, quality attributes, and net returns (Askew et al., 2002; Balkcom et al., 2010; Gwathmey et al., 2011; Jost and Cothren, 2000; Jost et al., 2008; Larson et al., 2007, 2009).

Balkcom et al. (2010) found that cotton plant growth and yield were affected marginally by row spacing, tillage system, and herbicide trait. They concluded that treatment effects on lint yield were influenced by growing season, and that narrow-row cotton could be beneficial for some producers depending on profitability of the system. Boquet et al. (2004) concluded utilization of conservation tillage and cover crops increases farm productivity through higher cotton yields. They also found that tillage, cover crops, and nitrogen rates had a significant influence on cotton quality attributes; however, they noted that differences were not of economic concern. Jost and Cothern (2000) completed a study on cotton yield differences planted in standard row spacing and ultra-narrow row spacing. They found that yields were higher for narrow row spacing in a dry growing season and the same across treatments in a wet growing season, with fiber length influenced by row spacing.

Economists routinely investigate profitability of cotton production systems. Larson et al. (2001) evaluated how cotton lint yield, nitrogen fertilization rates, production costs, and net revenues were affected by different winter cover crops and tillage decisions. Jost et al. (2008) made an economic comparison of transgenic and nontransgenic cotton production systems using experimental data from Georgia. Their main conclusion was that profitability was tied more closely to yields than with transgenic technologies.

The influence of production decisions on quality and yield has a direct impact on profitability. Because the price received by producers is based on quality attributes, excluding quality misrepresents the price received by producers. Britt et al. (2002) and Smith et al. (2003) described the relationship between production decisions, crop yield and quality, and profitability in two ways. Britt et al. (2002) examined profit variability and changes in profit with a decline in uncertainty related to weather for Texas cotton production. They estimated response functions for six outputs: cotton lint yield, cottonseed yield, micronaire, strength, staple, and turnout. Outputs were functions of rainfall, heat units, irrigation water, and fertilizer use, whereas quality price premiums or discounts were a function of quality. Response equations were linear specifications for all variables except for irrigation water and fertilizer use, which were specified as third-degree polynomials. Their overall results were that, if producers choose a profit maximizing set of inputs, while considering quality, and had access to perfect climate information, they would increase their profitability and minimize their risk. They identified the availability of only three years of experimental data, imperfections due to random errors, and differences between an experimental site and a working farm as several weaknesses in their model and data.

Although fiber quality attributes have been included routinely in agronomic studies, they have been treated as continuous variables and analyzed using analysis of variance, similar to yield (Bailey et al., 2003; Balkcom et al., 2006; Bauer and Busscher, 1996; Bauer and Roof, 2004; Jaime et al., 2013; Johnson et al., 2002; Schomberg et al., 2014). However, several fiber quality attributes are not continuous variables. They are categorical variables, such as color grade and leaf grade, or can be identified as categorical variables using a ratings scale, such as fiber strength and uniformity (Cotton Incorporated, 2013). There are alternate ways to analyze categorical data, such as ordered multinomial mixed logit models (Gbur et al., 2012; Hosmer et al., 2013; Jaeger, 2008). Using analysis of variance to analyze categorical variables can lead to results that are difficult to interpret and/or confidence intervals around the means that are outside of the data range (Gbur et al., 2012; Jaeger, 2008). More specifically, mixed logit models, a type of logistic regression, allows for both fixed and random effects. Logit models have been applied to agronomic and livestock data (Kyveryga et al., 2010; Landschoot et al., 2013; Osterstock et al., 2010; Reardon and Spurgeon, 2003; Wu et al., 2005); however, with one exception (Zhao et al., 2010) it is not evident that cotton fiber quality attributes have been analyzed in categories using logit analysis.

The objectives of this study were to evaluate the effect of row spacing, herbicide technology, and tillage on 1) the probability of obtaining a fiber quality and quality price difference, and 2) net returns. Cotton yield and fiber quality data for the analysis were from a three year experiment in Alabama. An ordered multinomial mixed logit model analysis of the data was used to achieve the first research objective. Partial budgeting and a linear mixed model analysis of data were used to achieve the second objective.

## MATERIALS AND METHODS

**Study Area and Experimental Design.** Seed cotton yield, ginning percentage, and fiber quality attribute data were obtained from an experiment at E.V. Smith Research Center near Shorter, Alabama (32°25.763′ N, 85°53.117′ W) on a Compass sandy loam (coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults). The experiment was initiated in the fall of 2003 and terminated after cotton harvest in 2006. The experiment remained in the same location, and treatments were not re-randomized each year. The experimental design was a split-split plot treatment restriction in a randomized complete-block design, replicated four times. Main plots were two row spacing options: 38 cm (narrow) and 102 cm (standard). Subplots were three cotton varieties representing three different herbicide technologies: nontransgenic (CV), glyphosate-tolerant (GL), and glufosinate-tolerant (GU). Sub-subplots were two tillage systems: conventional tillage (CVT) and conservation tillage (CST). The following paragraphs are a summary of the materials and methods employed in this experiment as outlined in Balkcom et al. (2010). The primary focus is on production activities that directly impacted variable costs associated with each treatment.

Each fall, 101 kg ha$^{-1}$ of rye (*Secale cereale* L.) was established in all plots, which were subsequently (except fall, 2003) paratilled following cover crop planting to eliminate the presence of subsurface soil compaction. Each year in February, the cover crop received 22 to 34 kg N ha$^{-1}$ as $NH_4NO_3$. The cover crop was chemically terminated 3 wk prior to the estimated date of cotton planting. After cover crop termination, two passes with a disk and one pass with a field cultivator occurred on CVT plots. On CST plots, cotton was planted directly into cover crop residue. Transition effects from conventional to conservation tillage were not a concern because CVT and CST plots had been in place for more than 15 yr.

All experimental plots were planted to cotton on 25 May 2004, 17 May 2005, and 17 May 2006. The parent line of the three herbicide technologies was Fibermax (Bayer Crop Sciences, Research Triangle Park, NC), and the varieties chosen were FM966® (CV), FM960 RR® (GL), and FM966 LL® (GU).The same varieties were utilized in all three years. Narrow-row plots were planted with a Great Plains® precision drill (Great Plains Mfg., Inc., Salina, KS), and standard-row plots were planted with a John Deere 1700 MaxEmerge Plus™ air planter (Deere & Co., Moline, IL). The seeding rate for the narrow-row plots was 25.9 plants/m$^2$ and 19.8 plants/m$^2$ for the standard-row plots. Fertilizer was applied as a split application with 47 kg N ha$^{-1}$ as $NH_4NO_3$ was applied as a starter prior to planting and an additional 67 kg N ha$^{-1}$ was side-dressed as urea-ammonium nitrate (UAN) for a total of 114 kg N ha$^{-1}$.

Herbicide applications were based on regional cooperative extension recommendations and varied based on tillage treatment and seed varieties. Each year after planting, plots with CVT and CV cotton treatments received Prowl® (1.67 L/ha; BASF Ag. Products, Research Triangle Park, NC) as a PRE. In 2004 and 2006, CV plots received a single POST application of Envoke® (0.01 L/ha; Syngenta Crop Protection, Inc. Greensboro, NC) and an application of Agri Star® Clethodim 2EC (1.17 L/ha; Albaugh, LLC, Ankeny, IA), and GL and GU plots received an application of Roundup Weathermax® (1.68 L/ha; Monsanto Company, St. Louis, MO) and Ignite® (2.34 L/ha in 2004 and 1.68 L/ha in 2005; Bayer Crop Science, Research Triangle Park, NC), respectively. In 2005, CV, GL, and GU plots received two applications of Staple® (1.2 L/ha; DuPont USA, Wilmington, DE), Roundup Weathermax (1.68 L/ha), and Ignite (2.34 L/ha), respectively. Standard-row plots received a layby application of Caparol® (2.33 L/ha; Syngenta Crop Protection, Inc., Greensboro, NC, USA) and MSMA® (3.11 L/ha; Drexel Chemical Company, Memphis, TN, USA) in all three years, and narrow-row plots received a layby application of Envoke (0.01 L/ha) in 2004 and 2005 and Staple (0.09 L/ha) in 2006.

Cotton was hand harvested on 4 October 2004, 11 October 2005, and 11 October 2006 after being defoliated with tribufos (1.17 L ha$^{-1}$) and thidiazuron (0.09 kg ha$^{-1}$), along with a boll opener (ethephon; 1.75 L ha$^{-1}$). Ginning percentage for a subsample of seed cotton from each plot was determined using a 20-saw tabletop micro-gin. Lint yield was estimated by multiplying ginning percentage by seed cotton yield. High volume instrument testing and hand-classing procedures at the former USDA-Agricultural Marketing Service classing office in Birmingham, AL was used to analyze the ginned material from each plot to establish fiber quality measurements. Plant population and lint yield data are discussed in detail in Balkcom et al. (2010).

**Analysis of Categorical Variables.** All fiber quality attributes were converted to a quality ratings scale (Table 1) for consistency and to better represent how the market treats fiber quality attributes (Cotton Incorporated, 2013). One is the highest category and six is the lowest category depending on the response variable. Associated frequencies of each categorical variable are included in Table 1. Summary statistics of each fiber quality attribute are displayed in Table 2. Color grade, leaf grade, staple length, and micronaire are identified typically as categorical variables; however, based on the frequency of data and quality price premium and discount structure, several categories were combined together. For example, color grades 41 and 51 were combined together into quality rating four. Typically, length uniformity, measured as a percentage, and strength, measured in grams tex$^{-1}$, are analyzed as continuous variables. For this analysis, following the fiber property ratings outlined by Cotton Incorporated (Cotton Incorporated, 2014), length uniformity and fiber strength were converted into categorical variables. Furthermore, the quality price difference was converted to a rating scale similar to the fiber quality attributes (Table 1).

**Table 1. Fiber quality attribute, categorical outcomes by quality rating, and associated frequencies**

| Quality Attribute | Quality Rating (1 = Higher Value and 6 = Lower Value) | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Color Grade | 11 | 21 | 31 | 41/51 | | |
| | *44*[z] | *47* | *20* | *33* | | |
| Leaf Grade | 1 | 2 | 3 | 4/5 | | |
| | *5* | *59* | *65* | *15* | | |
| Staple (1/32$^{nd}$ in.) | 38/39 | 36/37 | 35 | 34 | 33 | 31/32 |
| | *26* | *86* | *19* | *6* | *5* | *2* |
| Micronaire | 3.7 – 4.2 (premium) | 3.5-3.6 and 4.3-4.9 (base) | 3.4 and under or 5.0 and higher (discount) | | | |
| | *47* | *52* | *45* | | | |
| Strength (g/tex) | 33 and above (very strong) | 30-32 (strong) | 26-29 (Base) | 21-25 (weak) | 20 and below (very weak) | |
| | *101* | *33* | *9* | *1* | *0* | |
| Uniformity (%) | Above 85 (Very high) | 83-85 (High) | 80-82 (Average) | 77-79 (Low) | Below 77 (Very Low) | |
| | *16* | *53* | *59* | *16* | *0* | |
| Quality Price Difference (¢ kg$^{-1}$) | 8.82 and Above | 4.41 - 8.81 | 4.40 – 0 | Less than 0 | | |
| | *48* | *65* | *17* | *14* | | |

[z] Frequency (i.e., 44 out of 144 observations had a color grade of 11)

**Table 2. Summary statistics for fiber quality attributes, variables used in net return calculations, and net returns above variable treatment costs**

| Variable | N | Mean | Std Dev | Minimum | Maximum |
|---|---|---|---|---|---|
| Fiber Quality Attributes | | | | | |
| Color Grade | 144 | 24.06 | 11.60 | 11.00 | 51.00 |
| Leaf Grade | 144 | 2.65 | 0.77 | 1.00 | 5.00 |
| Fiber Staple Length (1/32$^{nd}$ inch) | 144 | 36.34 | 1.42 | 31.00 | 39.00 |
| Micronaire | 144 | 4.05 | .662 | .290 | .5700 |
| Uniformity (%) | 144 | 82.46 | 1.82 | 78.10 | 86.00 |
| Strength (g/tex) | 144 | 33.80 | 2.49 | 24.80 | 39.00 |
| Net Return Calculations | | | | | |
| Seed yield (kg ha$^{-1}$) | 144 | 2762 | 910 | 1202 | 5061 |
| Ginning percentage (%) | 144 | 41.32 | 1.67 | 37.86 | 46.56 |
| Cotton Lint (kg ha$^{-1}$) | 144 | 1135 | 360 | 504 | 2062 |
| Quality Price Difference (¢ kg$^{-1}$) | 144 | 6.60 | 5.00 | -12.90 | 12.10 |
| Net returns above variable treatment costs ($ ha$^{-1}$) | 144 | 1711.88 | 707.09 | 503.98 | 3532.96 |
| Net returns above variable treatment costs without quality ($ ha$^{-1}$) | 144 | 1635.07 | 677.35 | 453.56 | 3372.04 |

The variables converted to ordered multinomial categories were analyzed using the proportional odds model (Gbur et al, 2012; Hosmer et al, 2013; Stroup, 2013). For multinomial distributions with J ordered categories, there were J – 1 link functions relating the probability of a given treatment being in category j, where the probabilities were $\pi_1, \pi_2, \ldots, \pi$, to the linear predictor. Link functions for J categories were defined in matrix form as follows:

$$\boldsymbol{\vartheta}_1 = ln\left(\frac{\pi_1}{1-\pi_1}\right) = \vartheta_1 + \boldsymbol{X\beta} + \boldsymbol{Zb}; \quad (1)$$

$$\boldsymbol{\vartheta}_2 = ln\left(\frac{\pi_1+\pi_2}{1-(\pi_1+\pi_2)}\right) = \vartheta_2 + \boldsymbol{X\beta} + \boldsymbol{Zb}; \text{ and} \quad (2)$$

$$\boldsymbol{\vartheta}_{J-1} = ln\left(\frac{\pi_1+\pi_2+\ldots+\pi_{J-1}}{1-(\pi_1+\pi_2+\ldots+\pi_{J-1})}\right) = \vartheta_{J-1} + \boldsymbol{X\beta} + \boldsymbol{Zb}. \quad (3)$$

The linear predictors for N observations in J – 1 categories were $\boldsymbol{\vartheta}_1, \boldsymbol{\vartheta}_2, \ldots, \boldsymbol{\vartheta}_{J-1}$, and $\boldsymbol{\vartheta}_1, \boldsymbol{\vartheta}_2, \ldots, \boldsymbol{\vartheta}_{J-1}$ were the intercepts for the $J^{th}$ link. Matrix $\boldsymbol{X}$ is an $N \; x \; q$ matrix where $q$ is the number of fixed treatment effects. Vector $\boldsymbol{\beta}$ is a $q \; x \; 1$ vector of fixed effect parameters estimated by the model. Likewise, matrix $\boldsymbol{Z}$ is an $N \; x \; d$ matrix where $d$ is the number of random effects, and vector $\boldsymbol{b}$ is a $d \; x \; 1$ vector of random effects parameters estimated by the model. Using the inverse link function, response probabilities were obtained for each category. Assuming a three category model, inverse links were defined as:

$$\pi_1 = \frac{1}{1+e^{-\vartheta_1}}; \quad (4)$$

$$\pi_2 = \frac{1}{1+e^{-\vartheta_2}} - \frac{1}{1+e^{-\vartheta_1}}; \text{ and} \quad (5)$$

$$\pi_3 = 1 - \frac{1}{1+e^{-\vartheta_2}}. \quad (6)$$

Linear predictors and inverse links were estimated for each treatment effect. The use of inverse links allowed for results to be presented as cumulative probabilities.

Statistical analysis of categorical variables (fiber quality attributes and quality price difference) were performed using the generalized linear mixed model procedure (PROC GLIMMIX) in SAS Enterprise Guide 6.1 (SAS Institute Inc., Cary, NC) resulting in eight separate models. The multinomial distribution was selected as the response distribution and the cumulative logit was the link function for the proportional odds model for the ordered multinomial response variables (i.e., quality ratings for fiber quality attributes and quality price difference). Fixed effects were row spacing, cotton variety, tillage, and their interactions, whereas random effects were year and rep within year, which allowed for the broad assessment of treatment effects on quality over different environments (Blouin et al., 2011). Laplace's approximation, which uses maximum likelihood estimation, was applied to the eight models. Maximum likelihood estimation of parameters made it possible to formally test if there was significant year-to-year and within-replication variability using the COVTEST statement in PROC GLIMMIX. Estimates of linear predicators were converted to the cumulative probability scale using the ILINK option in PROC GLIMMIX. Contrasts were used for hypothesis testing, where statistical significance is applicable to the quality ratings as a group not an individual rating.

Initially, the analysis evaluated full models for the categorical variables; however, due to the lack of data to fit the full model as a multinomial distribution, the full model for each categorical response variable was simplified using a stepwise selection procedure where nonsignificant interactions were eliminated from the model. For example, not all combinations of row spacing and variety could be evaluated at the different tillage treatments. Preferred models had the lowest corrected Akaike Information Criterion (Kyveryga et al., 2010). Using this method, the models for leaf grade, micronaire, and quality price difference simplified to include only main treatment effects.

**Analysis of Net Returns Above Variable Treatment Costs.** A partial budgeting approach was used to evaluate the impact of row spacing, variety, and tillage on net returns above variable treatment costs (NR). Consideration was given to variable production costs that differed between treatments. The following equation was employed to estimate NR:

$$NR = \left\{\left(PL + \left(\frac{QD}{100}\right)\right) * LY\right\} + \left(\left(\frac{PC}{100}\right) * YC\right) - TC. \quad (7)$$

On the revenue side, $PL$ was the price of cotton lint (\$ kg$^{-1}$); $QD$ was the quality price difference (¢ kg$^{-1}$); $LY$ was cotton lint yield (kg ha$^{-1}$); $PC$ was the price of cottonseed (¢ kg$^{-1}$); $YC$ was the cottonseed yield (ton ha$^{-1}$); and $TC$ was variable treatment costs for each treatment (\$ ha$^{-1}$).

Cotton lint was defined as $LY = SY * GP$, where $SY$ was seed cotton yield (kg ha$^{-1}$); and $GP$ was ginning percentage. Subsequently, cottonseed yield ($CY$) is the difference between seed cotton yield ($SY$) and cotton lint yield ($LY$).

Seed cotton harvested from the experimental plots was not sold on the market; therefore, an actual market price was not available for the samples. The base price of cotton lint was set as the average Southeast spot cotton quotation of 1.82 \$ kg$^{-1}$for the 2013 to 2014 marketing year (USDA-AMS, 2014). The basic lint price was color 41, leaf 4, staple 34, micronaire 35 to 36 and 43 to 49, strength 26.5 to 28.4 g tex$^{-1}$, and uniformity of 81 units. The price received for cottonseed was 19 ¢ kg$^{-1}$, the average 2014 price received by producers in Alabama (USDA-NASS, 2015).

The following fiber quality attributes were used to calculate *QD* from the base price of cotton: color grade, leaf grade, staple length, micronaire, length uniformity, and strength. In this analysis, *QD* was defined as the sum of quality price premiums and discounts for the combination of color grade, leaf grade, staple length, micronaire, length uniformity, and strength. Quality price premiums and discounts were based on 2013 to 2014 season average spot cotton differences from the Southeast region (USDA-AMS, 2014).

Costs for each production option were estimated using practices and inputs that differ for each treatment (Table 3). All production costs reflect prices paid by producer in 2013 (MSU, 2013; USDA-NASS, 2015). Specifically, production costs were 1) seed costs and associated technology fees; 2) machinery and labor costs associated with tillage, planting, and harvesting; and 3) herbicide product and application. Ginning and hauling costs were a function of cotton lint yield and were assumed to be 24.25 ¢ kg$^{-1}$ of cotton lint (MSU, 2013). Interest on operating capital accumulated over six months' costs were based on an interest rate of 4.5%. Operating capital expenses were assumed to be production expenses that differed between treatments plus ginning and hauling costs. Remaining inputs, including cover crop establishment and termination, fertilizer, other pesticides (excluding herbicides), harvest aids, growth regulators, crop insurance, and scouting, were held constant across treatments and were not included in the partial budget. Conventional tillage followed by GU cotton planted in narrow rows had the highest production cost per hectare, not including ginning and hauling costs. Although GL cotton had the highest seed and technology cost, more expensive herbicides were associated with GU cotton.

**Table 3. Production costs by row spacing, tillage, and variety**

| Row Spacing | Tillage$^z$ | Variety$^y$ | Production Costs (\$ ha$^{-1}$) |
|---|---|---|---|
| Standard | CVT | CV | 406.80 |
| | | GL | 465.61 |
| | | GU | 509.83 |
| | CST | CV | 374.58 |
| | | GL | 405.08 |
| | | GU | 449.31 |
| Narrow | CVT | CV | 475.94 |
| | | GL | 532.26 |
| | | GU | 611.09 |
| | CST | CV | 443.72 |
| | | GL | 471.02 |
| | | GU | 549.86 |

$^z$ Conventional tillage (CVT), conservation tillage (CST)

$^y$ Nontransgenic (CV), glyphosate-tolerant (GL), glufosinate-tolerant (GU)

Statistical analysis of NR was performed using the generalized linear mixed model procedure (PROC GLIMMIX) in SAS Enterprise Guide 6.1 (SAS Institute Inc., Cary, NC). Analysis of variance was employed to determine if there were significant differences between treatments. Fixed and random effects were the same as in the proportional odds models, and Laplace's approximation was applied to the NR model. Tukey's HSD adjustment (DIFF option within the LSMEANS statement in PROC GLIMMIX) was used to compare least-squares means at $p \geq 0.05$.

## RESULTS AND DISCUSSION

Cumulative rainfall totals from planting date to harvest date were approximately 588 mm in 2004, 529 mm in 2005, and 341 mm in 2006. The 63-yr average (1950-2013) was 529 mm. Although rainfall totals in 2004 and 2005 were higher than in 2006, accumulated heat units were greater in 2005 and 2006 than in 2004.

The analysis of variance for fiber quality attributes are displayed in Table 4, and for quality price differences and NR are displayed in Table 5. There was significant ($p \leq 0.05$) year-to-year and within-replication variability for all fiber quality attributes, as well as quality price differences and NR, with the exception of within-replication variability for micronaire (data not shown).

**Table 4. Analysis of variance and variance-component estimates for fiber quality attributes**

| Fixed Effects | Color Grade | | | Leaf Grade | | | Staple | | |
|---|---|---|---|---|---|---|---|---|---|
| | DF[z] | F Value | Pr > F | DF | F Value | Pr > F | DF | F Value | Pr > F |
| Spacing | 1,125 | 0 | 0.9916 | 1,126 | 0.89 | 0.3468 | 1,121 | 0.01 | 0.9029 |
| Variety | 2,125 | 10.2 | <0.001 | 2,126 | 6.36 | 0.0023 | 2,121 | 3.22 | 0.0434 |
| Tillage | 1,125 | 14.3 | 0.0002 | 1,126 | 1.12 | 0.2913 | 1,121 | 11.98 | 0.0007 |
| Spacing*Tillage | 1,125 | 4.38 | 0.0383 | | | | 1,121 | 4.12 | 0.0446 |
| Variety*Tillage | | | | | | | 2,121 | 3.32 | 0.0394 |
| **Fixed Effects** | **Micronaire** | | | **Strength** | | | **Uniformity** | | |
| | DF | F Value | Pr > F | DF | F Value | Pr > F | DF | F Value | Pr > F |
| Spacing | 1,127 | 0.26 | 0.6086 | 1,122 | 2.07 | 0.1523 | 1,125 | 1.81 | 0.1807 |
| Variety | 2,127 | 8.11 | 0.0005 | 2,122 | 12.27 | <.0001 | 2,125 | 8.97 | 0.0002 |
| Tillage | 1,127 | 1.6 | 0.2088 | 1,122 | 3.25 | 0.0738 | 1,125 | 4.27 | 0.0409 |
| Spacing*Variety | | | | 2,122 | 3.86 | 0.0237 | | | |
| Spacing*Tillage | | | | | | | 1,125 | 4.28 | 0.0406 |
| Variety*Tillage | | | | 2,122 | 2.68 | 0.0724 | | | |

[z] Numerator degrees of freedom, denominator degrees of freedom

**Table 5. Analysis of variance and variance-component estimates for quality price difference, and net returns above variable treatment costs (NR)**

| Fixed Effects | Quality Price Difference | | | NR | | |
|---|---|---|---|---|---|---|
| | DF[z] | F Value | Pr > F | DF | F Value | Pr > F |
| Spacing | 1,126 | 0.73 | 0.3940 | 1,121 | 7.88 | 0.0058 |
| Variety | 2,126 | 4.06 | 0.0195 | 2,121 | 11.38 | <0.0001 |
| Tillage | 1,126 | 1.11 | 0.2948 | 1,121 | 0.01 | 0.9312 |
| Spacing*Variety | | | | 2,121 | 0.09 | 0.9130 |
| Spacing*Tillage | | | | 1,121 | 0.57 | 0.4500 |
| Variety*Tillage | | | | 2,121 | 0.11 | 0.8986 |
| Spacing*Variety*Tillage | | | | 2,121 | 0.31 | 0.7308 |

[z] Numerator degrees of freedom, denominator degrees of freedom

**Color Grade.** The color grade with the highest frequency of occurrence was color grade 21 (Table 1); however, spot cotton differences for color grade are the same for color grades 11 and 21. For both 11 and 21, 91 out of 144 observations were color grade 11 or 21. The mean color grade was 24.06 (Table 2), which has little meaning because color grade is a categorical variable.

Nontransgenic and GL cotton had a higher estimated probability of being graded for color in levels 11 and 21 than GU cotton (Table 6). Previous research found that cultivar had a significant impact on fiber reflectance and yellowness, the two components that quantify color (Porter et al., 1996). The estimated probability of fiber from cotton grown using the GL cotton being in color grade 11 and 21 was 0.0447 + 0.8957 = 0.9404. Color grades 11 and 21 are the highest color grades and receive the same quality premium. There was a statistically significant difference between the effects of CV and GL ($p$ = 0.0229); CV and GU ($p$ = 0.0045); and GL and GU ($p$ = < 0.0001).

In both narrow and standard row spacing for cotton, the use of CST produced the highest probability for 11 and 21 color grade cotton fibers (0.8572 and 0.9404, respectively; Table 6). There was no statistical difference between the effects of CVT and CST within narrow row spacing; however, within standard row spacing, there was a statistically significant difference between the effects of CVT and CST ($p$ = 0.0001, Table 6*)*. The effects of row spacing within tillage were not significantly different, which is similar to results reported by Nichols et al. (2004).

**Table 6. Estimated probabilities of color grade for variety and spacing by tillage interaction and *p*-values for associated contrasts**

| Estimated Probabilities | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Rating | Category | Variety[z] | | | Spacing by Tillage Interaction[y] | | | |
| | | | | | N | | S | |
| | | CV | GL | GU | CVT | CST | CVT | CST |
| Color Grade | | | | | | | | |
| 1 | 11 | 0.0127 | 0.0447 | 0.0023 | 0.0069 | 0.0175 | 0.0027 | 0.0447 |
| 2 | 21 | 0.8003[x] | 0.8957 | 0.4335 | 0.6934 | 0.8397 | 0.4701 | 0.8957 |
| 3 | 31 | 0.1863 | 0.0595 | 0.5600 | 0.2983 | 0.1423 | 0.5236 | 0.0594 |
| 4 | 41/51 | 0.0007 | 0.0002 | 0.0042 | 0.0014 | 0.0005 | 0.0036 | 0.0002 |

Contrasts[w]

| Variety | | |
|---|---|---|
| | GL | GU |
| CV | 0.0229 | 0.0045 |
| GL | | <0.0001 |

| Spacing by Tillage Interaction | | | | | |
|---|---|---|---|---|---|
| | CVT | CST | | N | S |
| | S | S | | CST | CST |
| N | 0.1398 | 0.1300 | CVT | 0.1380 | 0.0001 |

[z] Nontransgenic (CV), glyphosate (GL), and glufosinate (GU)

[y] Narrow spacing (N), standard spacing (S), conventional tillage (CVT) and conservation tillage (CST)

[x] Estimated probabilities in bold are the highest probabilities by treatment across fiber quality ratings

[w] Contrasts are interpreted as the difference between the treatments ($p \geq 0.05$).

**Leaf Grade.** Leaf grade 3 was the most frequent leaf grade across all observations (Table 1), followed by leaf grade 2. The mean leaf grade was 2.65, but, as with color grade, this has little meaning because leaf grade is a categorical variable (Table 2). Similar to color grade, GL cotton had the highest estimated probability (0.0195) of being in leaf grade 1, the highest leaf grade (Table 7). The probability of being in leaf grade 2 was highest for fiber from GL cotton. Both CV and GU cotton had a higher probability of being in the lower leaf grades than GL cotton. There was a statistically significant difference between the effect of CV and GU ($p = 0.0458$) and GL and GU ($p = 0.0005$); however, there was no statistical difference between the effect of CV and GL cotton (Table 7).

**Staple Length.** Yarn strength, yarn evenness, and spinning efficiency are all influenced by cotton fiber length (staple). An increase in staple length is associated with a positive increase in the cotton quality difference. Staple length is a genetic trait, but can be influenced by growing conditions (Bradow and Davidonis, 2000). A staple range of 36 to 37 had the highest frequency of occurrence (Table 1). The mean staple length was 36.34, which falls into the long staple class (Table 2).

**Table 7. Estimated probabilities of leaf grade for variety and *p*-values for associated contrasts**

| Estimated Probabilities | | | | |
|---|---|---|---|---|
| Rating | Category | Variety[z] | | |
| | | CV | GL | GU |
| Leaf Grade | | | | |
| 1 | 11 | 0.0127 | 0.0447 | 0.0023 |
| 2 | 21 | 0.8003[y] | 0.8957 | 0.4335 |
| 3 | 31 | 0.1863 | 0.0595 | 0.5600 |
| 4 | 41/51 | 0.0007 | 0.0002 | 0.0042 |

Contrasts[x]

| Variety | | |
|---|---|---|
| | GL | GU |
| CV | 0.0229 | 0.0045 |
| GL | | < 0.0001 |

[z] Nontransgenic (CV), glyphosate (GL), and glufosinate (GU)

[y] Estimated probabilities in bold are the highest probabilities by treatment across fiber quality ratings

[x] Contrasts are interpreted as the difference between the treatments ($p \geq 0.05$).

Variety and tillage fixed effects were statistically significant at $p \leq 0.05$. Furthermore, interactions between spacing and tillage and variety and tillage were also statistically significant (Table 4). The estimated probability for fiber with a staple length of 36/37 was greater than 0.72 regardless of spacing by tillage or variety by tillage treatment (Table 8). Narrow row with CST treatment had the highest estimated probability ($\pi_3 + \pi_4 + \pi_5 + \pi_6 = 0.2293$) of having a staple value less than 36, which is associated with a greater discount or a lower premium depending on color grade and leaf grade. Larson et al. (2009) concluded that ultra-narrow–row cotton reduced staple length when compared to standard-row cotton, which they attributed to different harvest methods. In this study, all plots were harvested in the same manner. There was no statistical difference between the effects of CVT and CST within narrow row spacing; however, within standard row spacing, there was a statistically significant difference between the effects of CVT and CST ($p = 0.0002$). The effects of row spacing within tillage were not significantly different (Table 8).

The interaction between GU and CVT had the highest probability ($\pi_3 + \pi_4 + \pi_5 + \pi_6 = 0.2585$) of staple values less than 36, followed by the interaction between GL and CVT ($\pi_3 + \pi_4 + \pi_5 + \pi_6 = 0.2071$). The interaction between GL and CST had the highest probability ($\pi_1 = 0.2498$) of staple values greater than or equal to 38 (Table 8).The effect of variety within tillage was significantly different for the effects of CV versus GU within CVT ($p = 0.025$) and GL versus GU within CST ($p = 0.0103$). Nichols et al. (2004) found differences between varieties depending on year; however, they did not consider different tillage methods. Within each variety, the effects of CVT versus CST were significantly different within GL cotton ($p = 0.0004$).

**Table 8. Estimated probabilities of staple for spacing by tillage interaction and variety by tillage interaction and *p*-values for associated contrasts**

Estimated Probabilities

| Staple Rating | Staple ($1/32^{nd}$ in.) | Spacing by Tillage Interaction[z] | | | | Variety by Tillage Interaction[y] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | | S | | CV | | GL | | GU | |
| | | CVT | CST | CVT | CST | CVT | CST | CVT | CST | CVT | CST |
| 1 | ≥ 38 | 0.0420 | 0.0191 | 0.0736 | 0.1407 | 0.0634 | 0.0767 | 0.0216 | 0.2498 | 0.0163 | 0.0509 |
| 2 | 36/37 | 0.8415[x] | 0.7517 | 0.8586 | 0.8252 | 0.8580 | 0.8583 | 0.7713 | 0.7331 | 0.7252 | 0.8518 |
| 3 | 35 | 0.0919 | 0.1755 | 0.0541 | 0.0274 | 0.0626 | 0.0519 | 0.1596 | 0.0138 | 0.1960 | 0.0771 |
| 4 | 34 | 0.0147 | 0.0317 | 0.0082 | 0.0040 | 0.0096 | 0.0079 | 0.0281 | 0.0020 | 0.0367 | 0.0121 |
| 5 | 33 | 0.0080 | 0.0178 | 0.0045 | 0.0022 | 0.0052 | 0.0042 | 0.0157 | 0.0011 | 0.0208 | 0.0065 |
| 6 | ≤ 32 | 0.0019 | 0.0043 | 0.0010 | 0.0005 | 0.0012 | 0.0010 | 0.0037 | 0.0002 | 0.0050 | 0.0016 |

Contrasts[w]

| Spacing by Tillage Interaction | | | | | |
|---|---|---|---|---|---|
| | CVT | CST | | N | S |
| | S | S | | CST | CST |
| N | 0.1193 | 0.1860 | CVT | 0.2636 | 0.0002 |

| Variety by Tillage Interaction | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | CVT | | CST | | | CV | GL | GU |
| | GL | GU | GL | GU | | CST | CST | CST |
| CV | 0.0892 | 0.0250 | 0.0524 | 0.4865 | CVT | 0.7487 | 0.0004 | 0.0568 |
| GL | | 0.6428 | | 0.0103 | | | | |

[z] Narrow spacing (N), standard spacing (S), conventional tillage (CVT) and conservation tillage (CST)

[y] Nontransgenic (CV), glyphosate (GL), and glufosinate (GU)

[x] Estimated probabilities in bold are the highest probabilities by treatment across fiber quality ratings

[w] Contrasts are interpreted as the difference between the treatments ($p \geq 0.05$).

**Micronaire.** Micronaire is the fiber quality attribute that measures fiber fineness and maturity. Moisture, temperature, sunlight, plant nutrients, and plant/boll populations all influence micronaire levels. There are three categories for micronaire: premium, base, and discount. Variety was the only statistically significant effect ($p \leq 0.05$, Table 4). Nontransgenic and GU cotton had similar probabilities of being in each micronaire category (Table 9), and the effect of variety was not significantly different for the effects of CV versus GU ($p = 0.8361$, Table 9). Glyphosate cotton had the highest probability of a micronaire rating of three, which translates into a quality price discount. The effects of both CV and GU were statistically different from the effect of GL ($p = 0.0004$ and $p = 0.0007$, respectively; Table 9). This is similar to Nichols et al. (2004) where they found a spacing-by-variety interaction; however, they used different varieties than were used in this study.

**Table 9. Estimated probabilities of micronaire for variety and *p*-values for associated contrasts**

| Estimated Probabilities | | | | |
|---|---|---|---|---|
| Micronaire Rating | Micronaire | Variety$^{z}$ | | |
| | | CV | GL | GU |
| 1 | 3.7-4.2 | **0.4185**$^{y}$ | 0.1391 | 0.3991 |
| 2 | 3.5-3.6 and 4.3-4.9 | 0.3990 | 0.3622 | **0.4061** |
| 3 | le 3.4 and ge 5.0 | 0.1825 | **0.4987** | 0.1948 |

| Contrasts$^{x}$ | | |
|---|---|---|
| | Variety | |
| | GL | GU |
| CV | 0.0004 | 0.8361 |
| GL | | 0.0007 |

$^{z}$ Nontransgenic (CV), glyphosate (GL), and glufosinate (GU)

$^{y}$ Estimated probabilities in bold are the highest probabilities by treatment across fiber quality ratings

$^{x}$ Contrasts are interpreted as the difference between the treatments ($p \geq 0.05$)

**Strength.** The interaction between spacing and variety was significant at $p \leq 0.05$ (Table 4). Nontransgenic cotton grown in narrow and standard rows and GU cotton grown in narrow rows had probabilities of being at the highest strength rating (strength measurement of 33 or above) of greater than 0.99, which is interpreted as strong (Table 10). Glyphosate (GL) cotton in both narrow and standard rows and GU cotton grown in standard rows had higher probabilities of lower strength ratings; however, across all treatments, the probability of a strength rating resulting in a positive quality price difference increase was greater than 0.98. This was expected based on frequency data (Table 1) where 134 out of 144 observations had strength measurements of at least 30.

The effect of variety within spacing was significantly different for the effects of CV versus GL and the effects of GL and GU within narrow row spacing ($p = 0.0002$ and $p < 0.0001$, respectively) and CV and GL and CV and GU within standard row spacing ($p = 0.0007$ and $p < 0.0082$, respectively; Table 10). When compared within variety, the effects of narrow row spacing versus standard row spacing were statistically different only for GU cotton ($p = 0.0057$; Table 10).

**Uniformity.** Cotton fiber with a uniformity index of 83 or above receives a quality price premium, whereas cotton fiber with a uniformity index of less than 83 is considered the base or receives a quality price discount. Variety and spacing by tillage interaction were statistically significant at $p \leq 0.05$ (Table 4). Nontransgenic cotton had the highest estimated probability ($\pi_1 + \pi_2 = 0.7692$) of having a uniformity rating of one or two, which is associated with a quality price premium (Table 11). There was no statistical difference between the effects of CV and the effects of GU ($p = 0.6790$; Table 11). The probabilities associated with the effects of CV and GL behaved differently ($p = 0.0001$), as did the probabilities associated with the effects of GU and GL ($p = 0.0004$). The estimated probability of GL cotton having a uniformity rating of one or two was 0.2945 (Table 11).

For the spacing-by-tillage interaction, effects of CVT were not significantly different from CST within narrow row spacing ($p = 0.9996$; Table 11); however, within standard row spacing, effects of CVT were different from CST ($p = 0.0055$; Table 11). Standard row spacing with CST had the highest probability of receiving a fiber quality premium ($\pi_1 + \pi_2 = .7319$; Table 11). Although Larson et al. (2009) did not consider different tillage treatments, they concluded that standard row spacing had higher uniformity percentages than ultra-narrow row spacing.

**Quality Price Difference.** The quality price difference is the sum of the fiber quality premiums and discounts (combination of color grade, leaf grade, staple, micronaire, strength, and uniformity) and was converted into a categorical variable for analysis purposes. The majority of observations had quality price differences between 4.41 and 8.80 ¢ kg$^{-1}$ (Table 1). Premiums associated with color grade, leaf grade, and staple made up the largest portion of the quality price difference, with an average increase of 3.30 ¢ kg$^{-1}$.

**Table 10. Estimated probabilities of strength for spacing by variety interaction and *p*-values for associated contrasts**

| Strength Rating | Strength (g/tex) | Spacing by Variety Interaction$^z$ | | | | | |
|---|---|---|---|---|---|---|---|
| | | CV | | GL | | GU | |
| | | N | S | N | S | N | S |
| 1 | 33 and above | 0.9907$^y$ | 0.9916 | 0.6670 | 0.7663 | 0.9936 | 0.8925 |
| 2 | 30-32 | 0.0091 | 0.0082 | 0.3208 | 0.2262 | 0.0062 | 0.1045 |
| 3 | 26-29 | 0.0002 | 0.0002 | 0.0118 | 0.0072 | 0.0002 | 0.0029 |
| 4 | 21-25 | 0.0000 | 0.0000 | 0.0004 | 0.0003 | 0.0000 | 0.0001 |
| 5 | 20 and below | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Contrasts$^x$

Spacing by Variety Interaction

| | CV | GL | GU |
|---|---|---|---|
| | S | S | S |
| N | 0.9277 | 0.5030 | 0.0047 |

| | N | | S | |
|---|---|---|---|---|
| | GL | GU | GL | GU |
| CV | 0.0002 | 0.7291 | 0.0007 | 0.0082 |
| GL | | <0.0001 | | 0.2284 |

$^z$Narrow spacing (N), standard spacing (S), nontransgenic (CV), glyphosate (GL), and glufosinate (GU)

$^y$ Estimated probabilities in bold are the highest probabilities by treatment across fiber quality ratings

$^x$ Contrasts are interpreted as the difference between the treatments ($p \geq 0.05$).

**Table 11. Estimated probabilities of uniformity for variety and for spacing by tillage interaction and *p*-values for associated contrasts**

| Uniformity Rating | Uniformity Index (%) | Variety$^z$ | | | Spacing by Tillage Interaction$^y$ | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | N | | S | |
| | | CV | GL | GU | CVT | CST | CVT | CST |
| 1 | Above 85 | 0.0028 | 0.0004 | 0.0023 | 0.0017 | 0.0017 | 0.0004 | 0.0023 |
| 2 | 83-85 | 0.7664$^x$ | 0.2941 | 0.7311 | 0.6691 | 0.6691 | 0.3452 | 0.7296 |
| 3 | 80-82 | 0.2293 | 0.6939 | 0.2648 | 0.3268 | 0.3268 | 0.6452 | 0.2663 |
| 4 | 77-79 | 0.0015 | 0.0116 | 0.0018 | 0.0024 | 0.0024 | 0.0092 | 0.0018 |
| 5 | Below 77 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

Contrasts$^w$

Variety

| | GL | GU |
|---|---|---|
| CV | 0.0001 | 0.6790 |
| GL | | 0.0004 |

Spacing by Variety Interaction

| | CVT | CST | | N | S |
|---|---|---|---|---|---|
| | S | S | | CST | CST |
| N | 0.0198 | 0.5924 | CVT | 0.9996 | 0.0055 |

$^z$ Nontransgenic (CV), glyphosate (GL), and glufosinate (GU)

$^y$Narrow spacing (N), standard spacing (S), conventional tillage (CVT) and conservation tillage (CST)

$^x$ Estimated probabilities in bold are the highest probabilities by treatment across fiber quality ratings

$^w$Contrasts are interpreted as the difference between the treatments ($p \geq 0.05$)

Similar to previously discussed fiber quality attributes, variety was the only fixed effect significant at $p \leq 0.05$ (Table 5). Nontransgenic cotton had the highest probability of a quality difference of 8.82 ¢ kg$^{-1}$ or above (Table 12). Glyphosate cotton had the highest probability of an overall quality price discount. The effects of CV cotton were significantly different from GL cotton ($p$ = 0.0058; Table 12). This follows the trend within fiber quality attributes where CV cotton had higher probabilities of better quality cotton, with the exception of color grade and leaf grade, than GL and GU cotton.

**Table 12. Estimated probabilities of price quality difference for variety and *p*-values for associated contrasts**

| Quality Price Difference Rating | Quality Price Difference (¢ kg$^{-1}$) | Variety$^{z}$ | | |
|---|---|---|---|---|
| | | CV | GL | GU |
| 1 | 8.82 or above | 0.4209 | 0.1874 | 0.2545 |
| 2 | 4.41 – 8.81 | 0.4842$^{y}$ | 0.5644 | 0.5631 |
| 3 | 0 – 4.40 | 0.0625 | 0.1529 | 0.1160 |
| 4 | less than 0 | 0.0324 | 0.0953 | 0.0664 |
| | Contrasts$^{x}$ | | | |
| | Variety | | | |
| | GL | GU | | |
| CV | 0.0058 | 0.0661 | | |
| GL | | 0.3347 | | |

$^{z}$ Nontransgenic (CV), glyphosate (GL), and glufosinate (GU)

$^{y}$ Estimated probabilities in bold are the highest probabilities by treatment across fiber quality ratings

$^{x}$ Contrasts are interpreted as the difference between the treatments ($p \geq 0.05$)

**Net Returns Above Variable Treatment Costs.** As shown in Table 13, average NR across all treatments and years was 1711.88 \$ ha$^{-1}$(SD = 707.09 \$ ha$^{-1}$). When quality price differences are not considered, average NR falls to 1635.07 \$ ha$^{-1}$(SD = 677.35 \$ ha$^{-1}$), underestimating net returns by 76.81 \$ ha$^{-1}$(SD = 57.94 \$ ha$^{-1}$) or 4.7%. When quality was not considered, NR was underestimated in 90% of the observations (130 out of 144). Depending on treatment, considering quality increased the price received by producers by 1.1 to 4.9%, based on 1.82 \$ kg$^{-1}$. A decrease (increase) in the cash price would increase (decrease) the impact of the quality price premium or discount. For example, when cotton lint price was assumed at 1.32 \$ kg$^{-1}$, considering quality increased the average price received by producers by more than 5%, as compared to 3.7% at 1.82 \$ kg$^{-1}$. On average, change in price was due primarily to color grade and staple length premium.

Spacing and variety had significant effects on NR at $p \leq 0.05$ (Table 5). Similar to Balkcom et al. (2010), interactions between treatments were not statistically significant. The strong spacing effect ($p$ = 0.0058; Table 5) observed for NR shows that NR from standard row spacing was 8.9% higher than narrow row spacing. Standard row spacing outperformed narrow row spacing by 52.70 \$ ha$^{-1}$ (Fig. 1). Whereas Balkcom et al. (2010) found equivalent or higher yields (depending on year) between narrow and standard row spacing, narrow row spacing had higher seeding, planting, and harvesting costs, as compared to standard row spacing, Larson et al. (2009) concluded that, although not statistically significant, nonirrigated standard row cotton with solid row configuration had numerically higher NR at 85 ¢ kg$^{-1}$ cotton lint than narrow row cotton with solid row configuration; however results were dependent on the price of cotton.

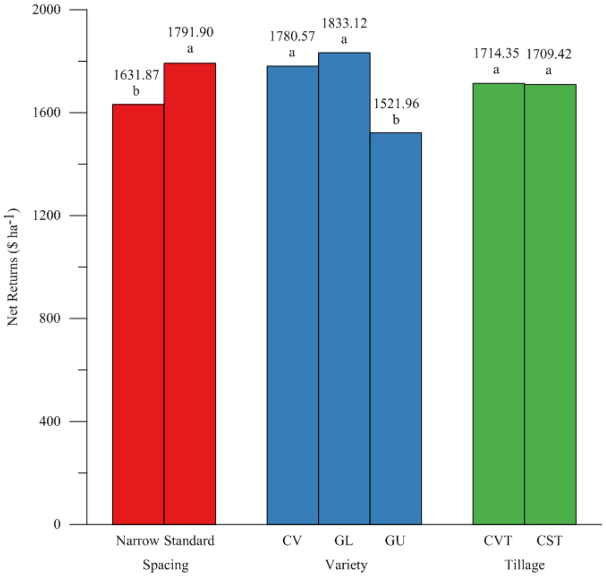

**Figure 1. Spacing [standard and narrow], variety [nontransgenic (CV), glyphosate (GL), and glufosinate (GU)], and tillage [conventional tillage (CVT) and conservation tillage (CST)] treatment effects on net returns above variable treatment costs (NR). Within treatments, bars with the same letter are not significantly different ($p$ = 0.05) based on Tukey's HSD adjustment (spacing SED = 57.011, DF = 121; variety SED = 69.823, DF = 121; tillage SED = 57.011, DF = 121, where SED is standard error difference of the mean and DF is degrees of freedom).**

**Table 13. Percent change in price received by producers by quality attribute and net returns with and without quality price premiums or discounts by row spacing, variety, and tillage**

| Spacing[z] | Variety[y] | Tillage[x] | Premium/Discount Average | Premium/Discount Std Dev | NR Average | NR Std Dev | NR without quality Average | NR without quality Std Dev | Change in NR Average | Change in NR Std Dev |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | ¢ kg$^{-1}$ | | $ ha$^{-1}$ | | | | | |
| Narrow | CV | CVT | 9 | 3 | 1632.11 | 728.80 | 1537.33 | 697.74 | -94.78 | 42.36 |
| | | NT | 8 | 2 | 1760.55 | 776.55 | 1668.49 | 745.86 | -92.06 | 38.06 |
| | GL | CVT | 6 | 5 | 1771.65 | 709.84 | 1699.43 | 666.27 | -72.21 | 61.03 |
| | | NT | 6 | 4 | 1767.66 | 621.40 | 1694.62 | 596.76 | -73.04 | 46.07 |
| | GU | CVT | 7 | 5 | 1434.43 | 503.86 | 1360.69 | 488.95 | -73.73 | 65.17 |
| | | NT | 7 | 6 | 1424.81 | 564.05 | 1359.46 | 560.51 | -65.35 | 67.68 |
| Standard | CV | CVT | 8 | 5 | 1903.03 | 824.75 | 1802.52 | 780.88 | -100.50 | 57.55 |
| | | NT | 8 | 3 | 1826.58 | 801.13 | 1738.67 | 777.36 | -87.91 | 35.26 |
| | GL | CVT | 2 | 9 | 1933.03 | 825.67 | 1891.56 | 761.11 | -41.47 | 98.57 |
| | | NT | 7 | 3 | 1860.14 | 660.15 | 1776.06 | 637.17 | -84.07 | 40.85 |
| | GU | CVT | 5 | 6 | 1611.86 | 789.11 | 1547.73 | 746.46 | -64.13 | 59.61 |
| | | NT | 7 | 5 | 1616.76 | 705.85 | 1544.25 | 687.98 | -72.50 | 55.46 |
| Average across treatments | | | | | 1711.88 | | 1635.07 | | -76.81 | |

[z] Narrow spacing (N) and standard spacing (S)

[y] Nontransgenic (CV), glyphosate (GL), and glufosinate (GU)

[x] Conventional tillage (CVT) and conservation tillage (CST)

Variety had the strongest effect on NR (Table 5). Net returns from GU cotton were significantly lower than NR from CV and GL cotton by 258.60 and 311.15 $ ha$^{-1}$, respectively (Fig. 1). There was no statistical difference between NR from CV and GL. Glufosinate cotton had a higher probability of a quality price difference greater than or equal to 4.41 ¢ kg$^{-1}$ than GL cotton (Table 12); however lower lint yields as well as higher variable treatment costs negated any gains from higher quality cotton. For CV cotton, higher quality price differences as well as lower variable treatment costs compensated for slightly lower average lint yields. Results are specific for varieties included in this study and should not be projected onto current stack-trait varieties; however, producers should give consideration to quality attribute potential, as well as yield, when choosing varieties, especially in years when the forecast is for lower cotton lint prices. Additional research is needed to determine how and if these results relate to current varieties.

Balkcom et al. (2010) concluded that there was an inconsistent response of lint yield to tillage; therefore, results did not support accepting the hypothesis that NR from CST was statistically greater than NR from CVT. There was no statistical difference between tillage treatments (Fig. 1), and the numerical difference in NR between CST and CVT was less than 2.00 $ ha$^{-1}$. Averaged over spacing and variety, NR from CST was less variable than CVT (Coefficient of Variation of 40.06 for CST and 42.78 for CVT).

## SUMMARY

The effects of row spacing, cotton variety, and tillage system were analyzed from 2004 to 2006 at the E.V. Smith Research Center near Shorter, AL. Fiber quality attributes and quality price difference were examined using an ordered multinomial mixed logit model, or, more specifically, a proportional odds model. Although applied to other agricultural topics, proportional odds models have not been utilized routinely to analyze fiber quality attribute data, nor quality price differences. Net returns were also examined as a response variable using a linear mixed model.

Overall, spacing and variety were influential in determining the levels of NR. Under the conditions of this study, narrow-row cotton was not the most profitable option for producers given the increase cost of seed and planting and harvesting costs. Nontransgenic and GU cotton had a higher probability of receiving a quality price difference of 4.41 ¢ $kg^{-1}$ or above (quality price difference ratings 1 and 2) than GL cotton; however GU cotton had the highest variable treatment costs of the three varieties included in the analysis. Standard row spacing and GL cotton had the numerically highest NR; however, GL cotton and CV cotton were not statistically different. Although CV cotton performed as well as GL cotton from a fiber quality and economic perspective, further research is required to determine if these results transfer to more current varieties. Conservation tillage is an economically viable option for cotton producers considering a transition to a more environmentally sustainable production system. Although impacts of CST on quality attributes were mixed, there was no difference (both numerically and statistically) between CVT and CST; however, there was less variability for CST.

## DISCLAIMER

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