COMPARISON OF PICKER AND STRIPPER HARVESTERS ON IRRIGATED COTTON ON THE HIGH PLAINS OF TEXAS

A Dissertation

by

WILLIAM BROCK FAULKNER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

August 2008

Major Subject: Biological and Agricultural Engineering

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ABSTRACT

Comparison of Picker and Stripper Harvesters on Irrigated Cotton on the High Plains of Texas. (August 2008)
William Brock Faulkner, B.S., Texas A&M University;
M.S. Texas A&M University
Chair of Advisory Committee: Dr. Bryan W. Shaw

Over a fourth of the cotton produced in the US since 2002 has been produced in Texas, with most coming from the High Plains. In recent years, Texas has accounted for almost half of all US cotton production (USDA-NASS, 2008b). Most cotton on the High Plains is of more storm-proof varieties that have traditionally been harvested using stripper harvesters. However, improvements in irrigation technology and shifting markets for US cotton have increased interest in picker harvesters in the region.

A holistic comparison of picker and stripper harvesters in irrigated cotton on the High Plains of Texas was conducted focusing on differences in system efficiencies, the costs of ginning, fiber and yarn quality, and potential economic returns under comparable crop yields and conditions.

Harvester performance was evaluated based on harvest efficiency, time-in-motion, and fuel consumption. Stripper harvesters left less cotton in the field, but most of the cotton left by the picker was of low quality. While the time spent in each operation of harvest was highly dependent on the operator and support equipment available, in general, picker harvesters were able to harvest a unit area of high-yielding cotton more quickly than stripper harvesters.

The cost of ginning picked and stripped cotton was evaluated considering current fee schedules from gins on the High Plains. On average, it cost a producer $4.76 more per bale to gin stripped-and-field-cleaned cotton than picked cotton.

Fiber quality parameters were compared between harvest treatments based on results from High Volume Instrument (HVI) and Advanced Fiber Information System (AFIS) tests. Samples were ring-spun into carded and carded-and-combed yarns. Differences in fiber quality between harvest treatments were more pronounced when growing conditions were less favorable. Few differences were detected in carded yarn quality between harvest treatments, while more pronounced differences favoring picked cotton were seen in carded-and-combed yarns.

A cost-benefit analysis was conducted to determine the production scenarios in which picker and stripper harvesters were most appropriate. Results indicate that, if a producer has sufficient yields coupled with sufficient area to harvest per machine, picker harvesting is a more profitable alternative to producers of on the High Plains.

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This research effort has, at times, been enjoyable, trying, stressful, and exciting, but in the end it has been incredibly rewarding. A project of this magnitude is rarely accomplished by the efforts of one individual, and this work is no exception. Many people have been integral to the success of this work. Some of them worked hard to achieve the results presented in this manuscript, while many more have labored to instill good character and a good work ethic in me for which I am incredibly grateful. While there is not enough space here to acknowledge all of them by name, I appreciate the patience and persistence they had, as well as the potential they seem to have found in me.

By the grace of God, He has allowed me to come to know and love His Son Jesus and has continued to bless me through many circumstances. I owe all to Him and hope to diligently live to bless Him in response to His kindness.

To my wife, Brittney, I want to say thank you for encouraging me, being patient with the many nights I've been away during harvest, and being excited with me as I have worked to complete this degree. Thank you for trusting me to provide for you and Emery, and thanks for being a great mother to our son. Your confidence in me has been a steady impetus to work at all things well. Marriage to you has been more fun than I could have imagined, and I look forward to tackling the challenges of the future with you by my side!

To my Mom, I want to say thank you for loving me and continuing to believe in me. Thank you for having the foresight to plan for C.W. and me to be able to go to college and for disciplining us to live and learn on our own. I know that raising two boys after Daddy died was hard, but (while I'm biased) I think you did a great job! Your wisdom and strength amaze me.

To my grandparents, I want to say thank you for teaching me to work hard and teaching me how important character and family are. If it weren't for you, I would not have come to love working in agriculture as much as I do. And, I remember well all of

the Little League games and elementary school plays that you came to, all of the weekends and summers I spent at the ranch, the 4-H projects and the family dinners. You have truly left an eternal legacy for all of your grandchildren.

To my brother, thanks for being a good friend and role model. You have a great wife and kids, and you have an incredible amount of godly wisdom! Thanks for telling me the truth, even when I don't think I want to hear it. And thanks for all of the listening and counseling that you've given me as we have done life together.

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And finally, thanks to the folks at Community Church for providing Brittney and me a great home. The friendships we've built as we have worked together to become the beautiful bride Christ came to redeem have changed us more than I would have ever imagined! Thanks for being supportive of Brittney, Emery, and me through some tough times and some great ones, too. "The body is not one member but many...and when one member suffers, all members suffer with it; when one member is honored, all parts rejoice." It's been an honor to be part of a church where that is lived out well.

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CHAPTER I

INTRODUCTION

Over a fourth of the cotton bales produced in the United States since 2002 have been produced in Texas with most of that cotton coming from the High Plains region, and in recent years, Texas cotton production has represented almost half of all the US cotton production (fig. 1). Owing to the harsh weather conditions of the region, most of the cotton on the High Plains is of more storm-proof varieties that have traditionally been harvested with stripper harvesters.

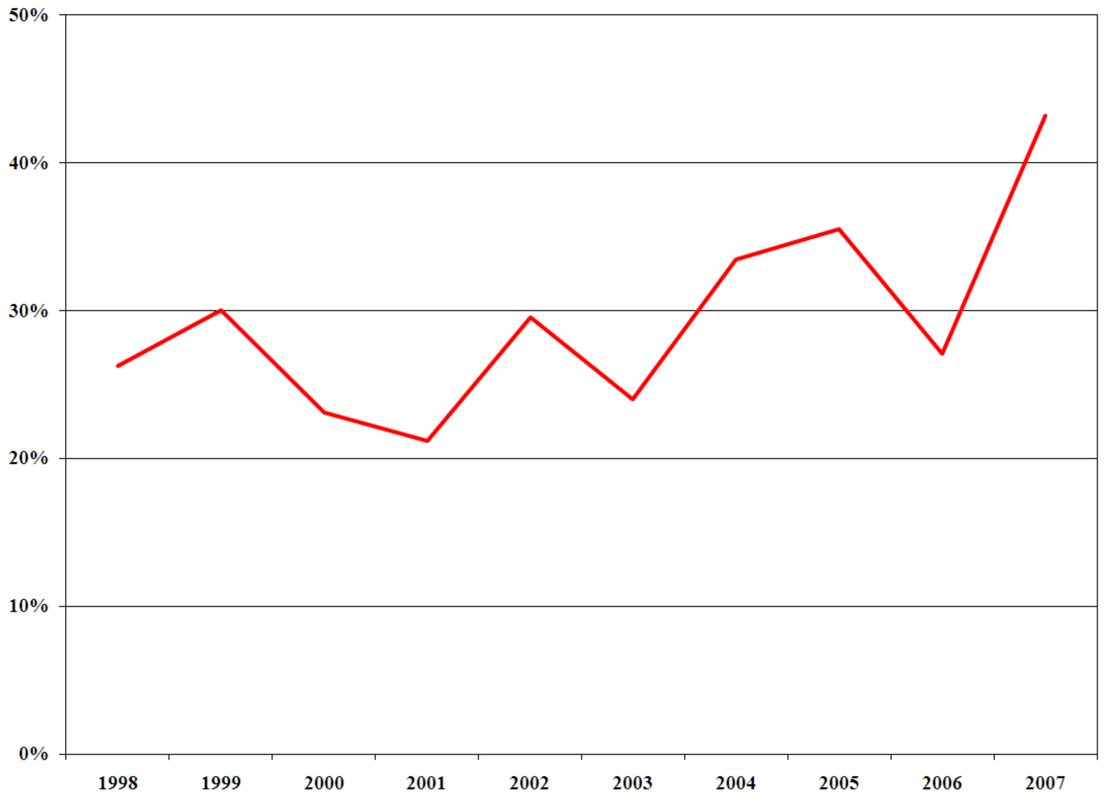


Figure 1. Percent of US cotton produced in Texas (USDA-NASS, 2008b).

This dissertation follows the format and style of *Transactions of the ASABE*.

Unlike picker harvesters, which use spindles to remove the seed cotton from the boll of the plant, stripper harvesters use brushes and paddles that indiscriminately remove seed cotton, bolls, leaves, and many branches from the stem of the plant. As a result, stripper harvested cotton contains more foreign matter than cotton harvested with pickers. This increased foreign matter leads to higher transportation costs per bale to haul modules to the gin as well as potentially higher costs of processing the cotton, due to the use of additional cleaning machinery at the gin. The indiscriminate harvest by stripper harvesters also leads to increased harvest of immature bolls that would be left in the field by a picker harvester. These immature bolls can lead to lower micronaire values, which may affect dye uptake, and subsequently lower strength, which can adversely affect spinning performance at the textile mill.

Stripper harvesters have several advantages over picker harvesters, including significantly lower purchase prices, fewer moving parts in the row units leading to lower fuel consumption and maintenance requirements, and removal of more cotton from the plant. Picker harvesters, however, pick cleaner cotton, are perceived to maintain fiber quality characteristics better than strippers, and may be able able to harvest cotton at higher speeds in high yielding stands.

As irrigation technology has improved and new cotton varieties have been introduced and adopted on the High Plains, yields in the region have dramatically increased, sometimes reaching 9.8 to 12.3 bales/ha (4 to 5 bales/ac). It is estimated that between 120,000 and 160,000 ha (300,000 and 400,000 ac) of drip irrigation has been installed on the High Plains in the past ten years for cotton production and over 450,000 ha (1.1 million ac) are irrigated with center pivot systems equipped with high efficiency application packages. Given these increases in yield, picker harvesters may be able to harvest irrigated cotton faster and more efficiently than stripper harvesters.

Furthermore, as more US cotton is being exported to foreign markets, production of a high quality crop is imperative. The base loan quality grade for cotton in the US is strict low middling 2.70 cm (1-1/16 in.) (41-4-34; i.e. color grade = 41, leaf grade = 4, staple = 34) compared to the Cotton Outlook A index (international base) of middling

2.78 cm (1-3/32 in.) (31-3-35) (table 1). The international base also has a higher tenacity requirement, a tighter micronaire range, and a higher uniformity index.

Table 1. Fiber quality base grades.

	US Base	International Base
Staple[a]	34	35
Tenacity (g/tex)	26	28
Micronaire	3.5-4.9	3.8-4.6
Uniformity Index (%)	80-82	82-83
Color	41	31
Leaf Grade	4	3

[a] Staple = 0.79 mm (1/32 in)

Foreign textile mills continue to raise their standards for fiber quality as cotton spinners are forced to compete with synthetic fibers that are not plagued with fiber contamination and degradation. Currently, High Plains cotton is often discounted by textile mills because of perceived difficulties in spinning cotton grown in this region. If the problems in spinning result from the low micronaire and strength contributed by immature bolls or the increased cleaning required to remove excess foreign material, picker harvested cotton from the High Plains may be more competitive with similarly graded cottons grown in other regions of the US cotton belt.

Cotton harvest is a critical time for producers on many fronts. Costs associated with harvest are a major portion of production costs; harvesting machinery is often the single largest cost of production; and the timing and method of harvest can dramatically impact crop quality and yield. For these reasons, a significant amount of research has been conducted regarding harvester evaluation. However, none of these studies individually has provided enough information to effectively compare harvest systems, particularly as they relate to the recent changes in production on the Texas High Plains.

OBJECTIVE

The objective of this research is to comprehensively compare picker and stripper cotton harvesters in irrigated cotton on the High Plains of Texas. Specifically, this research focuses on comparing:

1. Differences in system efficiency between picker- and stripper-based systems, including harvest efficiency and time-in-motion,
2. Differences in the costs of ginning between picked and stripped cotton, including seed cotton transportation and energy costs during ginning,
3. Differences in fiber and yarn quality between cotton harvested with different harvest systems, and
4. The potential economic returns for picker- and stripper-based systems on comparable crop yields and conditions.

Each of these components is used to perform a cost-benefit analysis to determine the production scenarios in which picker and stripper harvesters are most appropriate.

CHAPTER II

FIELD SITE DESCRIPTIONS

INTRODUCTION

Field work was conducted in a total of six fields at four different sites on the High Plains in 2006 and 2007. When possible, time-in-motion studies were conducted while harvesting on a typical field scale, while most of the seed cotton sampling and harvest efficiency tests occurred while harvesting smaller plots. Observations were made during the 2006 and 2007 harvest seasons on the High Plains with a six-row John Deere 9996 picker harvester with Pro-16 row units and a John Deere 7460 brush stripper.

SITE 1

In 2006, sampling was conducted at a field approximately 24 km west of Plains, Texas. The field was located on a Brownfield fine sand, and Stoneville 4554 Bollgard II® Roundup Ready Flex® (ST 4554 B2RF) was planted on 76 cm (30 in.) centers. Cotton was irrigated with a center-pivot irrigation system and had an average yield of 5.4 bales/ha (2.2 bales/ac based on 220 kg [480 lbs] bales). The picker was operated by employees of the producer and was equipped with scrapping plates on both front and rear drums. A six-row stripper was operated by a custom harvester.

Twelve plots, each 12 rows wide, were assigned one of three harvest treatments in a completely randomized design. Row lengths were determined with a measuring tape. Harvest treatments included picker harvesting, stripper harvesting with field cleaning, and stripper harvesting without field cleaning (fig. 2).

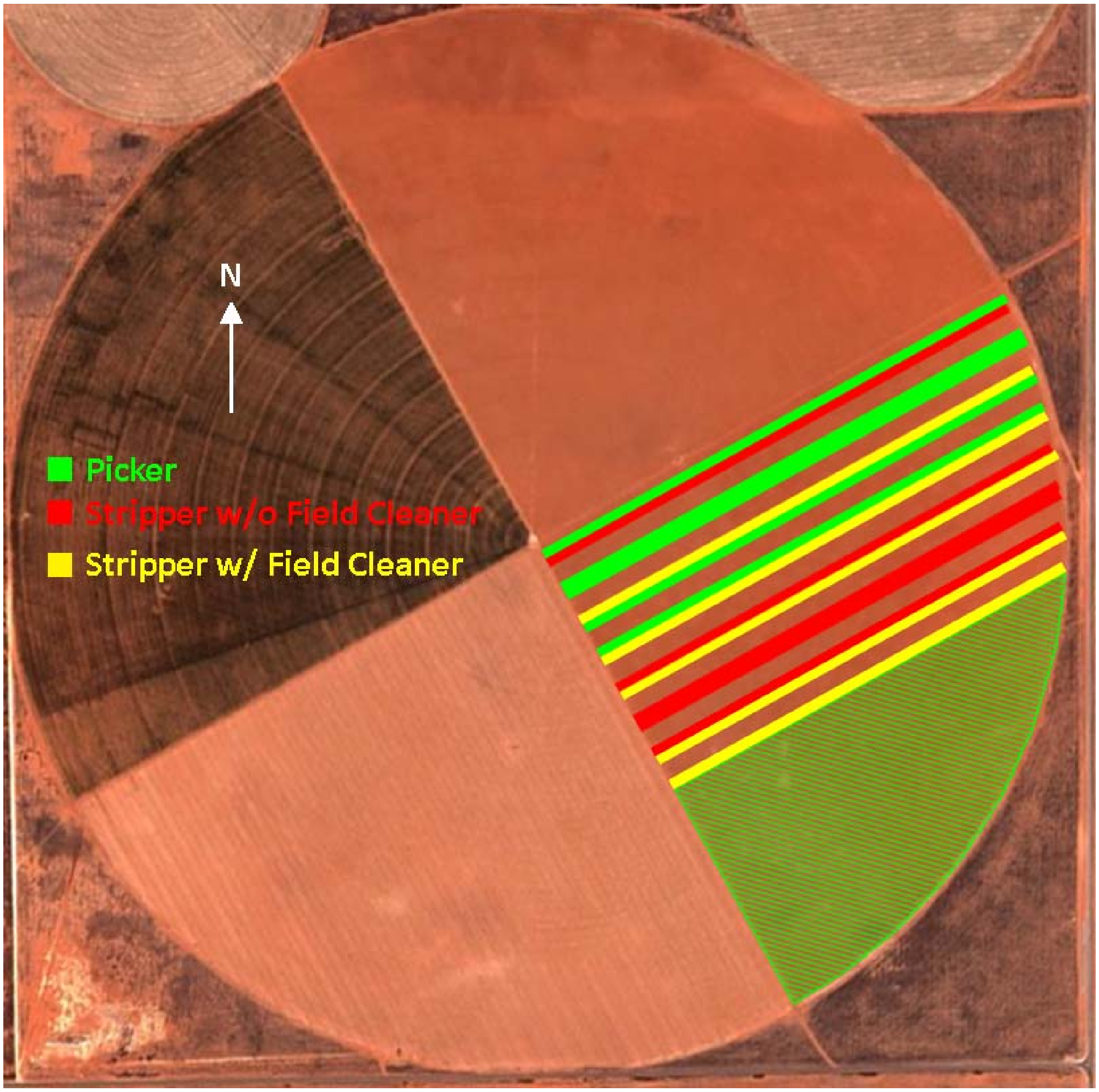


Figure 2. Sampling site 1.

Harvest efficiency tests were conducted and seed cotton samples collected from the solid- colored plots (fig. 2). Before being dumped into a module builder, a weigh wagon was used to determine the total mass of seed cotton from each harvester basket and from each plot. A 1.0 kg sample of seed cotton was collected from each plot for fractionation analysis, and a 140 kg sample was collected from each plot for fiber quality and spinning tests.

Seed cotton moisture content samples were collected from all plots at the time of harvest. Cotton was placed in sealed moisture cans, and seed cotton moisture was determined by a standard oven-drying method (ASTM, 2006). An analysis of variance test was conducted on sample moisture contents with the General Linear Model function in SPSS (SPSS 14.0, SPSS Inc., Chicago, Ill.) with the null hypothesis ($\alpha = 0.05$) that the moisture content of all samples was equal. Means were compared with the Least Significant Difference (LSD) pair-wise multiple comparison test. No significant differences were detected in moisture content samples between harvest treatments. The average moisture content was $6.59\%_{wb}$.

After removing the 140 kg samples, a full-size module was also built from the remaining cotton from all plots within each harvest treatment. Modules were ginned at New-Tex Gin in Plains, Texas, where the turnout, electrical consumption, and natural gas consumption were recorded for each module.

Time-in-motion data for the stripper treatments were collected from the same plots as the harvest efficiency tests. For the picker, additional time-in-motion data were collected from the southeast corner of the field (indicated by the striped green area in fig. 2). One Big 12 boll buggy and one module builder were included in each harvest system with a single harvester.

SITE 2

In 2007, sampling was conducted at three sites. The first was a field approximately 6 km east of Wilson, Texas. The field was located on an Amarillo loam, and FiberMax 9063 Bollgard II® Roundup Ready Flex® (FM 9063 B2RF) was planted on 102 cm (40 in.) centers. Cotton was irrigated with a sub-surface drip irrigation system and had an average yield of 9.23 bales/ha (3.74 bales/ac). The picker was operated by Texas A&M University (TAMU) personnel and was equipped with scrapping plates on the rear drums. Scrapping plates on the front drums were removed due to excessive choke-ups during harvest. An eight-row stripper was operated by the farm owner a week after picking.

Harvest efficiency and moisture content samples were collected and detailed time-in-motion and plant height data recorded for the picker at Site 2. The average moisture content of the cotton at time of picking was $4.69\%_{wb}$. Plant height data were collected by measuring the distance from the cotyledon to the terminal node of ten plants in five different plots. The average plant height at Site 2 was 72.0 cm (28.3 in.).

One Sam Stevens boll buggy and one module builder were included in each harvest system with a single harvester. The area that was picker harvested is shown in fig. 3. Rows were laid out in an east-west configuration. Due to time conflicts between stripper harvesting at Site 2 and harvesting at other locations, only a limited amount of time-in-motion data were collected for the stripper in the remainder of the field.

SITE 3

The second site where sampling was conducted in 2007 included two fields approximately 17 km northwest of Muleshoe, Texas. Both fields were located on a Friona loam soil and planted on 76 cm (30 in.) centers. Cotton was irrigated with a center-pivot irrigation system.

Harvest efficiency tests were conducted and fiber samples collected from the first field, which was used for variety trials. Four varieties were included in the harvester comparison study, including FiberMax 9058 Flex® (FM 9058 F), FM 9063 B2RF, PhytoGen™ 485 Widestrike™ Roundup Ready Flex® (PHY 485 WRF), and ST 4554 B2RF. The field was planted in a randomized complete block fashion with three replications for each variety (fig. 4). Each plot consisted of 12 rows of cotton. The first 240 m (800 ft) of six rows in each plot were harvested with a picker harvester while the remainder of each plot was harvested with a six-row stripper with a field cleaner. The side of the plot that was picked was randomly selected for each plot. The picker was operated by TAMU personnel and was equipped with scrapping plates on the rear drums. The stripper was operated by a custom harvester.

Figure 3. Sampling site 2.

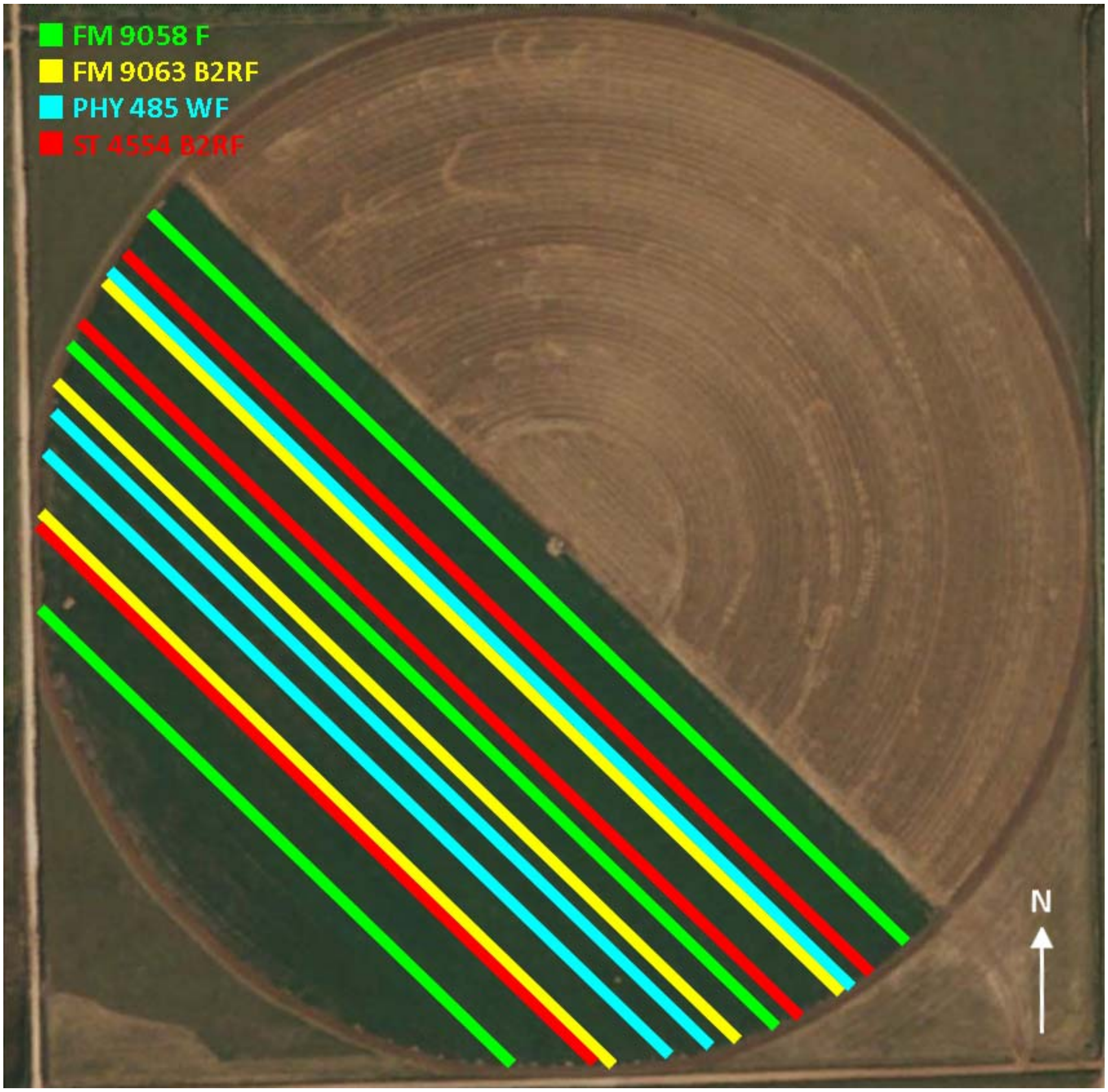


Figure 4. Sampling site 3 - variety trials.

Before being dumped into a module builder, a weigh wagon was used to determine the total mass of seed cotton from each harvester basket and from each plot. A 1.0 kg sample of seed cotton was collected for each harvest method in each plot for fractionation analysis, and a 140 kg sample was collected for both harvest methods in each plot for fiber quality and spinning tests.

Seed cotton moisture content samples were collected for both harvest treatments within each plot at the time of harvest and analyzed by the same method as in 2006. No significant differences were detected in moisture content samples between harvest treatments within a given variety or between varieties within a given harvest treatment. The average moisture content for all samples at Site 3 was $4.93\%_{wb}$. Plant height data were also collected from each plot for each harvest treatment. No significant differences were detected in plant height between harvest treatments or variety at Site 3. The average plant height at Site 3 was 57.4 cm, which was smaller than at Site 2 ($p = 0.001$) and Site 4 ($p = 0.035$).

Time-in-motion data were collected from a second field at Site 3 planted in FiberMax 960 Bollgard II® Roundup Ready (FM 960 B2R). The field was planted in a circular fashion (fig. 5) and had an average yield of 6.2 bales/ha (2.5 bales/ac). The stripper was operated without the field cleaner, and both the picker and stripper were operated in 2nd gear. The picker and stripper operated in tandem and shared the use of three KBH Mule Boy boll buggies and two module builders. The boll buggies were able to take three basket dumps from the stripper before unloading into the module builder, but they were only able to take one dump from the picker basket. Because the boll buggies were not equipped with a hydraulic vane packer, dumping from the picker into the boll buggy took substantially longer at Site 3 because the boll buggy operator had to tip the buggy half way through the transfer process to make additional room for cotton coming from the picker basket. This required a break in the unloading operation, drastically increasing the dump time from the picker for this location. GPS integrated with the time-in-motion data recording program were used to determine row lengths and the area harvested per basket dump.

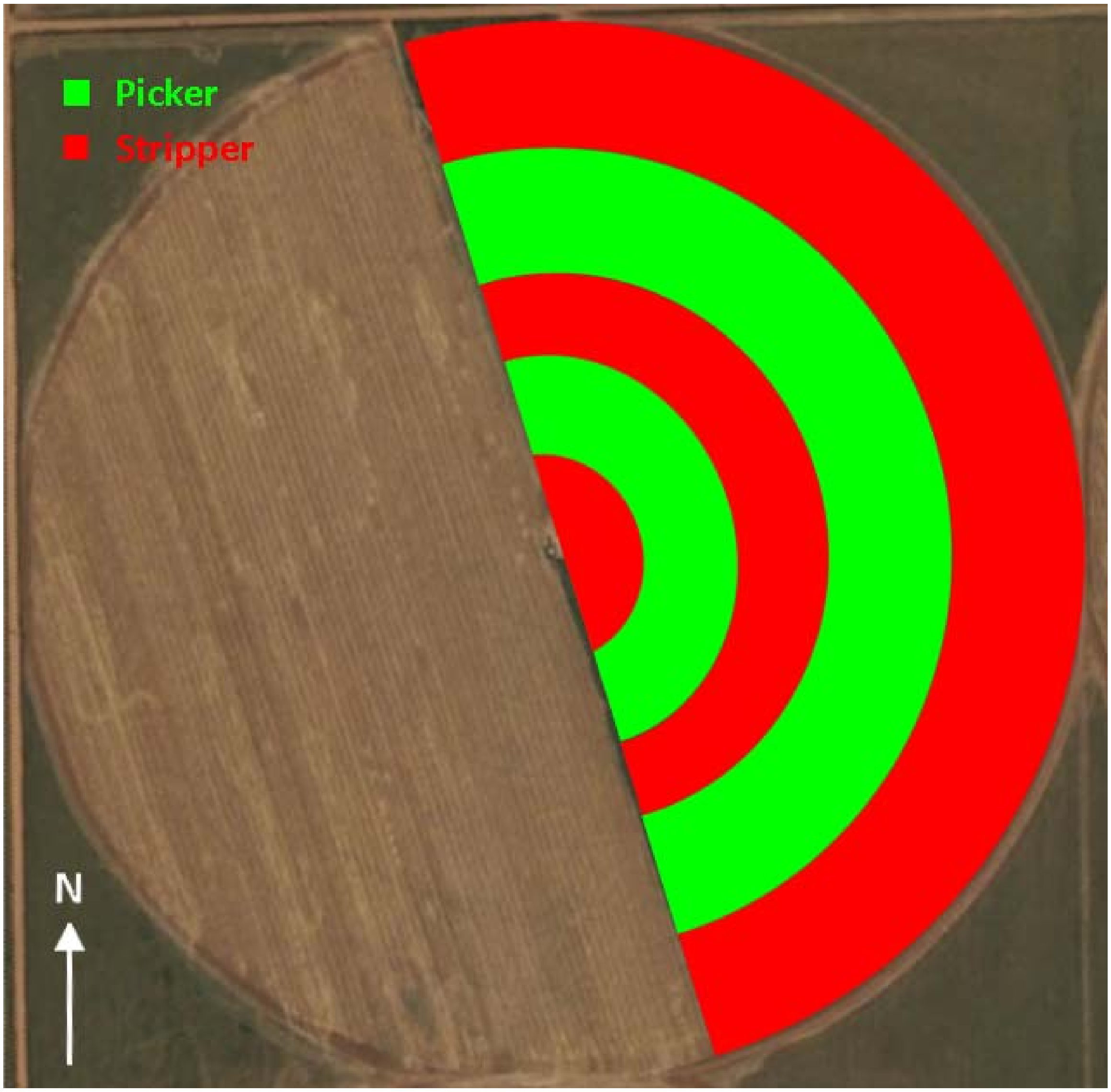


Figure 5. Sampling site 3 - time-in-motion.

SITE 4

The third site where sampling was conducted in 2007 included two fields approximately 19 km east of Plains, Texas. Both fields were located on a combination of Amarillo fine sandy loam and Amarillo loamy fine sand planted on 102 cm (40 in.) centers. Both fields were irrigated with center-pivot irrigation systems.

Harvest efficiency tests were conducted and fiber samples collected from the first field, which was used for variety trials. The same four varieties harvested from Site 3 were included in the harvester comparison at Site 4. Again, the field was planted in a randomized complete block fashion with three replications for each variety (fig. 6). As at Site 3, each plot consisted of 12 rows of cotton. The first 170 m (550 ft) of six rows in each plot were harvested with a picker harvester while the remainder of each plot was harvested with a six-row stripper with a field cleaner. The side of the plot that was picked was randomly selected for each plot. The picker was operated by TAMU personnel and was equipped with scrapping plates on the rear drums. The stripper was operated by employees of the farm owner.

Sampling at Site 4 was conducted in a similar manner to Site 3. No significant differences were detected in moisture content samples between harvest treatments within a given variety, with the exception of FM 9063 B2RF, for which the moisture content of the picked cotton ($4.63\%_{wb}$) was lower ($p = 0.041$) than the stripped cotton ($5.66\%_{wb}$). Given the similarity in management practices and soil type combined with the lack of differences in all other varieties, the difference in moisture content between picked and stripped treatments of FM 9063 B2RF would likely dissappear with a greater sample population. No differences were detected in moisture content between varieties within a given harvest treatment. The average moisture content for all samples at Site 4 was $5.62\%_{wb}$, which was significantly higher ($p = 0.01$) than the moisture content of samples at Site 3.

No significant differences were detected in plant height at Site 4 between harvest treatments within a given variety or between varieties at Site 4. The average plant height

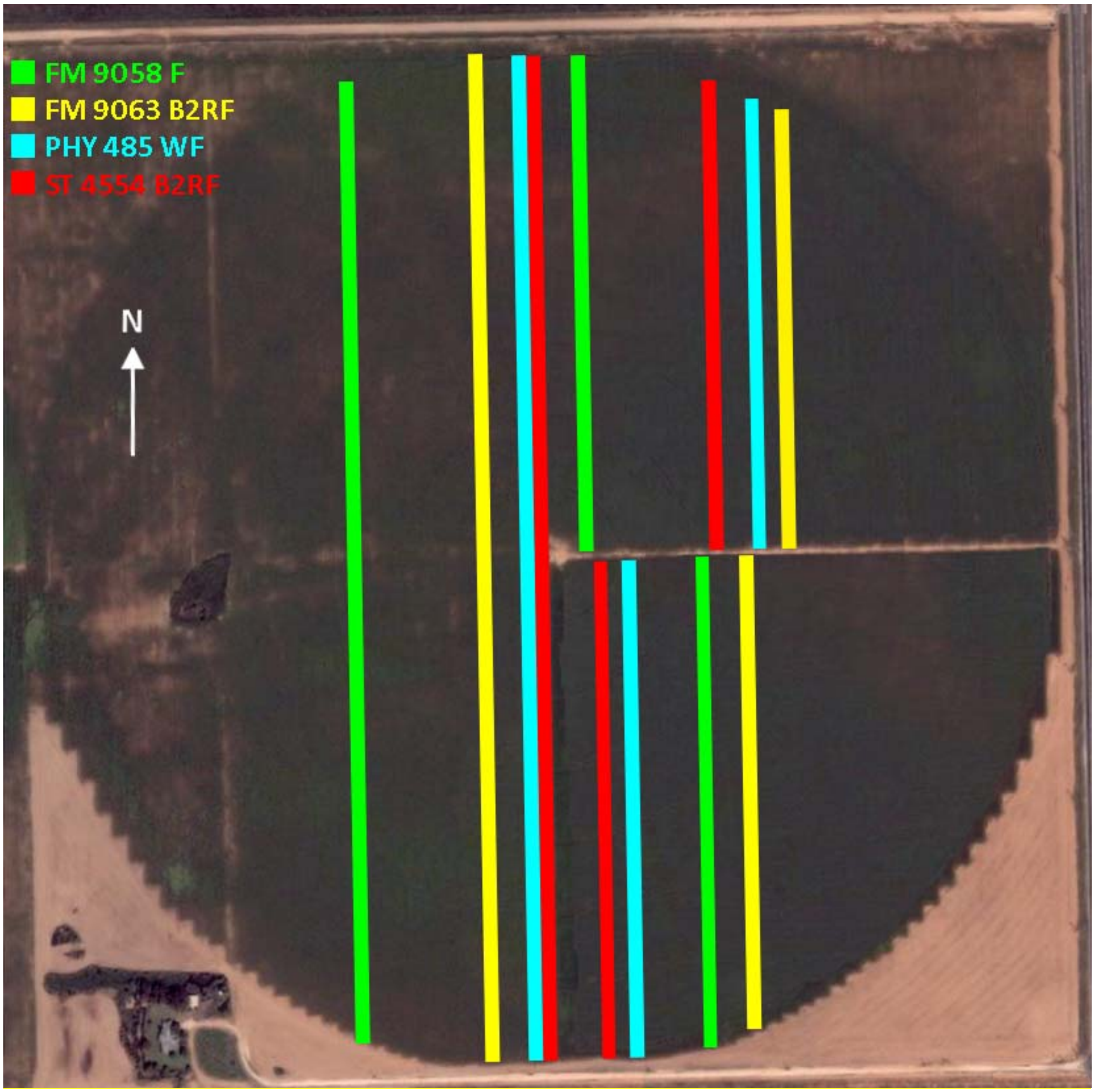


Figure 6. Sampling site 4 - variety trials.

at Site 4 was 79.8 cm, which was significantly higher ($p < 0.0005$) than the average plant height at Site 3.

Time-in-motion data were collected from a second field at Site 4 (fig. 7) planted in FiberMax 955 LibertyLink® Bollgard II® (FM 955 LLB2). Cotton was planted beyond the edge of the center pivot system, but most of the field was irrigated. The field average yield was 8.15 bales/ha (3.3 bales/ac). The stripper was operated with the field cleaner engaged. The picker and stripper operated in tandem and shared the use of one boll buggy and one module builder. Access to the boll buggy was the bottleneck in the harvest system. Again, the boll buggy was able to take three basket dumps from the stripper before unloading into the module builder but only able to take one dump from the picker basket. GPS integrated with the time-in-motion data recording program were used to determine row lengths and the area harvested per basket dump.

Figure 7. Sampling site 4, time-in-motion.

CHAPTER III
HARVESTER PERFORMANCE

INTRODUCTION

Harvesting cotton efficiently in the modern era requires a complex system involving many machines and skillful machinery management. Aerial or ground applicators are often used to apply one or more harvest aids, including desiccants and boll-openers. Picker or stripper harvesters remove seed cotton from the plant, which is then transferred directly to a module builder or to a boll buggy for transport to the module builder. Once a module is built and tarped, module trucks transport seed cotton to the gin. To maximize the profitability of an operation, machinery must be selected and operated to maximize the utility of each component of the harvest operation.

Harvester performance in the field is critical to ensure timely harvest for quality preservation and efficient use of labor and capital resources. Harvester performance can be measured in many different ways, all of which affect the profitability of a production operation.

Time-in-motion

The time spent during each stage of harvest is a good indicator of the efficiency of a given system. During a typical harvest, time may be spent harvesting, turning the harvester onto the next set of rows, waiting for the boll buggy to position to receive seed cotton from the harvester, dumping the basket, or in downtime for maintenance and repair. Producers have a narrow window during which to harvest their crop to avoid quality degradation that comes with time and exposure to harsh weather conditions after the boll opens. Harvest can be delayed for wet weather or field conditions; high wind; and, in the case of strippers, high relative humidity.

Because producers face a limited time frame during which to harvest their crop at peak quality, it is desirable to increase the proportion of time spent harvesting versus the other necessary tasks enumerated above. Limited data exists on the time spent during each segment of the cotton harvest. Chen et al. (1992) developed a model to predict the overall cost of harvest for different equipment combinations in the Mississippi Delta region, but the conditions in this region are significantly different than for the High Plains, and stripper harvesters were not included in the evaluation. Willcutt and Barnes (2008) reported that traditional six-row harvesters utilizing boll buggies have a field efficiency of approximately 70% (i.e. 70% of the time spent in the field is spent picking cotton). The remaining 30% of time was spent in support operations such as turning at the end of the row, waiting for boll buggies, transferring seed cotton, and maintaining row units. When no boll buggies were used, field efficiency was reduced to 49%.

Fuel Use

The amount of fuel used per unit of production directly affects the profitability of a production operation. Nelson et al. (2001) estimated that stripper harvesters use approximately 190 L (50 gal) of diesel per day and operate for 10 hr/d, but he did not report on the yield or area harvested per hour. Matthews et al. (1982) reported that diesel-powered brush strippers consumed 9.1 L/ha (0.98 gal/ac). Willcutt and Barnes (2008) measured fuel consumption of machinery from several typical six-row cotton harvesting operations. Using a six-row John Deere 9976 picker to harvest cotton that averaged 5.4 bales/ha (2.2 bales/ac), they reported average fuel consumption of 17.0 L/ha (1.82 gal/ac), equivalent to 3.14 L/bale (0.83 gal/bale).

Harvest Efficiency

Harvest efficiency is an important factor for evaluating harvester performance because it is a measure of the amount of cotton in the field that is harvested and subsequently cleaned, ginned, and made available for marketing. Machine harvesting of cotton has led to lower harvest efficiencies, but the gains in labor efficiency have far surpassed the losses in harvest efficiency, resulting in complete conversion of the US cotton industry to mechanical harvesters. Because stripper harvesters are less discriminating than picker harvesters, it would be expected that stripper harvesters would have higher harvest efficiency. Williford et al. (1994) reported that spindle pickers may harvest at up to 95% efficiency but typically achieve efficiencies between 85 and 90%, whereas stripper harvesters can have efficiencies up to 99%. However, the cotton left unharvested by a spindle picker is often less mature, having lower micronaire values and subsequently being weaker. Reductions in harvest efficiency can be the result of cotton being left on the plant or being knocked off the plant onto the ground. Both methods of loss represent unmarketable lint for the producer.

Several studies have compared the seed cotton and lint yields of cotton harvested with both pickers and strippers. Brashears and Hake (1995) compared results from two varieties of cotton harvested with a two-row spindle picker and a four-row brush-roll stripper with and without a field cleaner. Varieties tested include Paymaster HS26 (considered a "stripper variety") and Stoneville 132 (an early maturing "picker variety"). Significant differences were found between the yield of seed cotton and turnout of all harvest methods, while there was no significant difference between lint yield for the stripper with field cleaner and stripper without field cleaner for either variety. As expected with a less discriminating harvest method, the lint yield for both stripper treatments was higher than the lint yield for the picker harvester for both varieties tested.

The analysis conducted by Brashears and Hake (1995) did not measure the amount of cotton left in the field; therefore while the stripper harvester harvested more lint than the picker harvester, harvest efficiency between the machines was not compared. Furthermore, the two-row picker utilized in this study does not reflect the advances in technology nor capacity of modern harvest machinery, making application of this study to modern production systems questionable. The harvest yield in this study was also less than five bales/ha (2 bales/ac), further confounding application of the results of this study to new varieties of irrigated cotton on the High Plains.

Vories and Bonner (1995) reported results from a similar experiment comparing spindle picked versus stripped-and-field-cleaned dry-land cotton in Arkansas. Again, significant differences were detected in seed cotton yield and turnout, but harvest efficiency was not reported. As with the picker in the Brashears and Hake (1995) study, the brush stripper used in the Vories and Bonner (1995) study (an Allis Chalmers 880 with alternating brushes and flaps) does not represent modern harvesting machinery. And again, the yields in this study were all below five bales/ha (2 bales/ac).

Faircloth et al. (2004) did a more comprehensive comparison of harvest methods on irrigated cotton in northeast Louisiana, looking at several varieties. The picker harvesters used in this study varied by location, but only one brush stripper (equipped with a field cleaner) was used in all locations. In year one of this study, there was no difference in lint yield between harvest methods for any location or variety. However, in year two, differences were detected at all locations with the stripper harvested cotton yielding higher than the picker harvested cotton. The average yield across all experiments was 5.2 bales/ha (2.1 bales/ac), with the highest reported yield being 6.7 bales/ha (2.7 bales/ac) with the brush stripper in year two. Again, no absolute comparison of harvest efficiency was conducted.

Yates et al. (2007) reported results from a comparison of picker and stripper systems on the Texas High Plains, showing increased lint yield by the stripper harvester. Again, no absolute measure of harvest efficiency was made, and yields averaged 2.5 bales/ha (1.0 bale/ac) in year one and 6.4 bales/ha (2.6 bale/ac) in year two. The same picker harvester was used in the Yates et al. (2007) study as in the Brashears and Hake (1995) study so that similar limitations exist regarding the applicability of this study to modern production systems.

METHODS

For this study, picker and stripper harvesters were compared based on time-in-motion, fuel usage, harvest efficiency, and the foreign matter content of seed cotton at several locations throughout the High Plains.

Time-in-motion

Time-in-motion data were collected for each harvest system by an observer riding in the cab of the harvester at the four sites described in Chapter II. A macro in Microsoft

Excel was used to record a time stamp at the beginning and end of each of the following operations:

- Begin row
- End row
- Start turn at end of row
- End turn at end of row
- Stop harvest for full basket
- Begin transfer of cotton to boll buggy
- End transfer of cotton to boll buggy
- Start down time
- End down time

The time spent in each operation for each harvest system was calculated and compared. Basket capacity (in bales) was determined by comparing the number of basket dumps made into each module by the number of bales produced from each module at the gin.

Fuel Use

Fuel use was measured by filling harvesters full of diesel before commencing harvest operations. After harvest operations, a commercially-available fuel meter (Model MD130; Great Plains Industries, Inc.; Wichita, KS) was used to determine the volume of diesel consumed by measuring the volume required to refill the harvester's diesel tank to a predetermined level. The corresponding area harvested was measured manually in 2006 and by GPS in 2007.

Harvest Efficiency

Harvest efficiency tests were conducted to determine the amount of seed cotton left in the field by each harvester. In 2006, all observations were made in a field planted in ST 4554 B2RF. In 2007, observations were made on four distinct varieties at three locations.

Before mechanical harvesting, locations within each experimental field were randomly selected and marked (fig. 8). At each assigned location, all seed cotton on all plants within a 3.0 m (10 ft) length of row was hand harvested to determine the yield of seed cotton in that portion of the field. Approximately 1.5 m (5 ft) from the end of the hand harvested row, a second 3.0 m (10 ft) length was marked and the furrow space cleaned of any seed cotton to determine the harvest efficiency of the mechanical harvester by assuming that the yields in both 3.0 m sections were equal. After mechanical harvesting, all of the cotton left on the plants within the second 3.0 m (10 ft) length was collected, and any cotton lying on the ground was also collected separately.

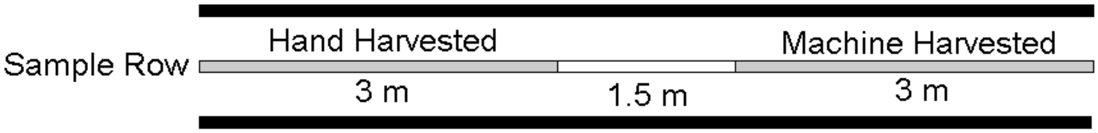


Figure 8. Schematic of harvest efficiency test plots.

The mass of cotton left on the plant and that knocked off the plant were used to determine harvest efficiency (eq. 1)

$$\eta = \left[1 - \frac{P+G}{H}\right] x100\% \tag{1}$$

where: η = harvest efficiency (%),

P = mass left on plants in 3.0 m length of mechanically harvested row (g),

G = mass on ground in 3.0 m length of row after mechanical harvest (g), and

H = mass of cotton hand harvested in 3.0 m length of row.

An analysis of variance test was conducted on harvest efficiencies with the General Linear Model function in SPSS (SPSS 14.0; SPSS Inc., Chicago, Ill.) with the null hypothesis ($\alpha = 0.05$) that all harvest efficiencies were equal. Means were compared with the Least Significant Difference (LSD) pair-wise multiple comparison test.

Seed cotton moisture content samples were collected from all plots at the time of harvest as described in Chapter II. Plant height was measured in all plots in 2007 as described in Chapter II. Correlations were tested between harvest efficiency and both seed cotton moisture and plant height with Pearson's two-tailed correlation test ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Time-in-motion

As expected, the amount of time spent in each harvest operation was highly dependent on the harvester operator and the amount of support equipment (e.g. boll buggies and module builders) available at each location. Average time-in-motion data collected from each site (excluding outliers) are shown in table 2. Due to the number of covariates, time-in-motion data did not lend themselves to statistical analysis.

Table 2. Time-in-motion data.

Harvester	Location	Yield (bales/ha [bales/ac])	Speed (km/h [mph])	Basket Capacity (bales)	Dump Time (s)	Turn at End of Row (s)
Picker	Site 1	5.4 (2.2)	6.4 (4.0)	--	77	20
	Site 2	9.1 (3.7)	6.0 (3.7)	4.60	49	23
	Site 3	6.2 (2.5)	7.7 (4.8)[a]	3.99	104	45
	Site 4	8.1 (3.3)	5.8 (3.6)	5.85	--	42
	Avg.			**4.81**	**76**	**32.5**
S. w/ FC[b]	Site 1	4.9 (2.0)	6.0 (3.7)	1.98	54	27
	Site 2	9.1 (3.7)	4.5 (2.8)[c]	--	--	--
	Site 4	8.1 (3.3)	4.8 (3.0)	2.26	36	36
	Avg.			**2.12**	**45**	**31.5**
S. w/o FC[d]	Site 1	5.9 (2.4)	5.5 (3.4)	1.79	54	31
	Site 3	6.2 (2.5)	8.9 (5.5)[a]	1.79	20	27
	Avg.			**1.79**	**37**	**29.0**

[a] Harvested in 2nd gear
[b] S. w/FC = stripper with field cleaner
[c] Data from 8-row stripper with field cleaner
[d] S. w/o FC = stripper without field cleaner

The smaller basket capacity on the stripper required more frequent transfer of stripped cotton to a boll buggy compared to the picker, but the transfer process was faster due to the dumping mechanism on the stripper compared to a floor chain transfer system on the larger picker basket. As previously mentioned, the dump time for the picker at Site 3 was substantially longer than at Sites 1 and 2 because the boll buggies at this site were not equipped with a hydraulic vane packer, so the boll buggy operator had to tip the buggy half way through the transfer process to make additional room for cotton coming from the picker basket. The additional transfer time at Site 3 points to the number of variables that can affect the efficiency of harvest operations as well as the need for evaluation of the complete harvest system when comparing harvester operation.

The results of a simulation of the time spent harvesting, transferring cotton, and turning at the end of the row is shown in table 3, assuming no harvester down time and 915 m (3000 ft) rows planted on 76 cm (30 in) centers. Average harvester basket capacities and dump times from table 2 were assumed. Because there was no practical difference between harvest systems in the amount of time spent turning at the end of the row, an end-row turn time of 30 s was assumed for all harvesters.

Table 3. Time-in-motion simulation.[a]

	Picker	Stripper w/FC	Stripper w/o FC
3.7 bales/ha (1.5 bales/ac)			
Speed (kph [mph])	7.7 (4.8)	8.9 (5.5)	8.9 (5.5)
Harvest time (hr/ha [hr/ac])	0.320 (0.130)	0.289 (0.117)	0.289 (0.117)
Harvesting (%)	88.7	85.6	85.7
Transferring (%)	5.1	7.6	7.4
Turning (%)	6.2	6.9	6.9
7.4 bales/ha (3.0 bales/ac)			
Speed (kph [mph])	6.1 (3.8)	4.8 (3.0)	5.1 (3.2)
Harvest time (hr/ha [hr/ac])	0.411 (0.166)	0.518 (0.210)	0.488 (0.198)
Harvesting (%)	87.2	87.7	87.2
Transferring (%)	7.9	8.5	8.7
Turning (%)	4.8	3.8	4.1
9.9 bales/ha (4.0 bales/ac)			
Speed (kph [mph])	5.6 (3.5)	4.5 (2.8)	4.8 (3.0)
Harvest time (hr/ha [hr/ac])	0.453 (0.183)	0.565 (0.229)	0.531 (0.215)
Harvesting (%)	86.0	86.1	85.6
Transferring (%)	9.6	10.3	10.7
Turning (%)	4.4	3.5	3.7

[a] Simulation assumes no harvester downtime.

In general, due to the larger basket capacity, in high-yielding stands, the picker was able to harvest a unit area of cotton more quickly than was either stripper. This advantage was compounded when extremely high yielding cotton was field-cleaned due to limitations on the flow rate of seed cotton processed through the field cleaner. In lower yielding cotton where the field cleaner was not the bottleneck in the system, the stripper was able to harvest at a faster rate than the picker, giving it an advantage in terms of area harvested per unit time.

Fuel Use

The average fuel consumption for the picker in 2006 and 2007 was 26.2 L/ha (2.80 gal/ac). No correlation was detected between fuel use per unit area and yield. The measured fuel consumption in this study was approximately 55% higher than that reported by Willcutt and Barnes (2008). However, Willcutt and Barnes (2008) observed fuel consumption from a John Deere 9976 harvester, which has a 250 horsepower engine, while observations in this study were from a John Deere 9996 harvester, which has a 350 horsepower engine. The ratio of fuel use to engine rated horsepower were roughly equivalent in both studies. Because the stripper harvesters were operated by custom harvesters, insufficient data on stripper fuel use was collected to draw any conclusions from field measurement. However, all stripper harvesters had 175 HP engines, from which it may be deduced that, under similar engine loads, the fuel consumption for strippers would be approximately half that of the John Deere 9996 picker harvesters.

Harvest Efficiency

Analyzing data from all plots for each harvester, no correlations were detected between harvest efficiency and moisture content (n = 29), plant height (n = 24), or yield (n = 29). Overall differences in harvest efficiency were detected between harvest methods ($p < 0.0005$) but not by sampling location or variety. Average harvest efficiencies from all sites are shown in table 4.

Table 4. Harvest efficiency.

Harvest Method	Harvest Efficiency[a] (%)
Picker	95.3 a
Stripper w/ Field Cleaner	97.8 b
Stripper w/o Field Cleaner	98.5 b

[a] No differences were detected ($\alpha = 0.05$) in values in the same column followed by the same letter.

For a given harvest method, no differences were detected between varieties or locations. While they demonstrate that pickers, on average, leave more cotton in the field, these tests do not give an indication of the maturity and value of the remaining seed cotton.

CONCLUSIONS

Harvester performance was measured as a function of time-in-motion, fuel consumption, and harvest efficiency at four irrigated sites on the High Plains. Time-in-motion performance was highly dependent on equipment used in the harvest system and machinery operators. In a system where sufficient support equipment such as boll buggies and module builders were available, although stripper harvesters have smaller basket capacity than pickers, strippers spent more time harvesting than pickers in lower yielding cotton. In higher yielding cotton, pickers spent more time harvesting than strippers. Field cleaner capacity severely limited stripper ground speed in high yielding cotton.

Fuel consumption for a six-row John Deere 9996 picker was 26.2 L/ha (2.80 gal/ac). No correlation was detected between fuel use per unit area and yield.

The John Deere 9996 picker was shown to have statistically lower harvest efficiency than the John Deere 7460 stripper regardless of variety or harvest location. However, these tests gave no indication of the quality or value of cotton left unharvested by the picker. If the cotton left unpicked is immature, the value of lint per unit area may be greater for picked cotton even though less cotton is harvested.

CHAPTER IV
GINNING

INTRODUCTION

Mechanical methods of separating cotton lint from the seed have been around for centuries. The Churka gin was a rudimentary machine that used rollers to pinch fibers from the seed. In 1794, Eli Whitney received a patent for a cotton gin that used metal spikes in concentric rows to pull cotton fibers through a narrow slot that seeds could not fit through. In 1796, Henry Ogden Holmes received a patent for a gin employing metal saws rather than spikes and "ribs" that allowed cleaned seeds to fall out the bottom of the gin. These improvements, which first allowed for continuous flow ginning, represent the principle on which modern gin stands function (Mayfield and Anthony, 1994).

In 1834, Alex Jones developed the first successful mechanical feeder for the cotton gin. The first half of the 20th century saw the development of seed cotton dryers and cleaners as well as lint cleaners (Mayfield and Anthony, 1994). Today, most gin facilities employ a labyrinth of machinery to automatically feed and disperse seed cotton modules; pneumatically convey seed cotton between machinery stages; regulate seed cotton moisture for cleaning and ginning; separate lint from seeds; clean, compress, and package lint; and weigh and convey cotton seed. While the machinery specifications and sequences in each gin differ, all gins have the same goal of preserving fiber quality while removing foreign matter and seed from the lint in a timely manner without wasting lint.

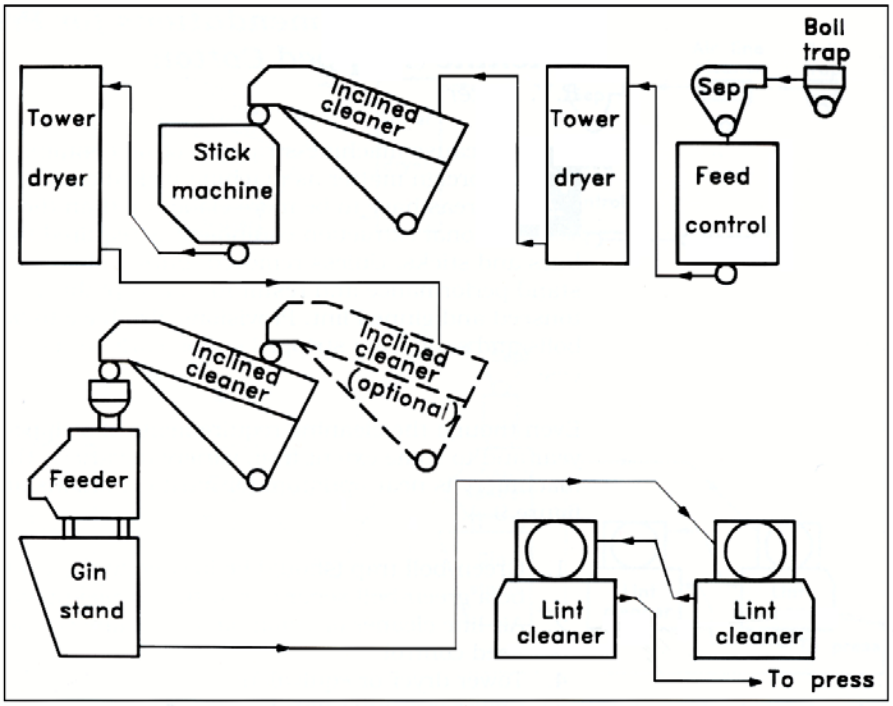
Foreign matter in seed cotton may include sticks, burrs, leaf, grass, or other objects. Increased foreign matter in seed cotton results in more modules of seed cotton per unit area, resulting in greater seed cotton transportation costs and more required cleaning at the gin. Because of the indiscriminate manner in which stripper harvesters remove seed cotton from the plant, stripped cotton generally has more foreign matter than picked cotton. Field cleaners were added to strippers to reduce the amount of foreign material in the module, but stripped-and-field-cleaned seed cotton generally contains more foreign matter than picked seed cotton.

While each gin is unique, typical machinery sequences for modern saw gins processing upland picker and stripper cotton are shown in fig. 9. Due to the increased foreign matter content of stripped cotton, a gin processing stripped cotton typically has an extra stage of seed cotton cleaning compared to a gin processing picked cotton. Non-field-cleaned stripped cotton typically has approximately 320 kg (700 lbs) of foreign matter per bale compared to 45 kg (100 lbs) for picked cotton (table 5). Stripped cotton that has been field-cleaned typically has approximately 180 kg (400 lbs) of foreign matter per bale.

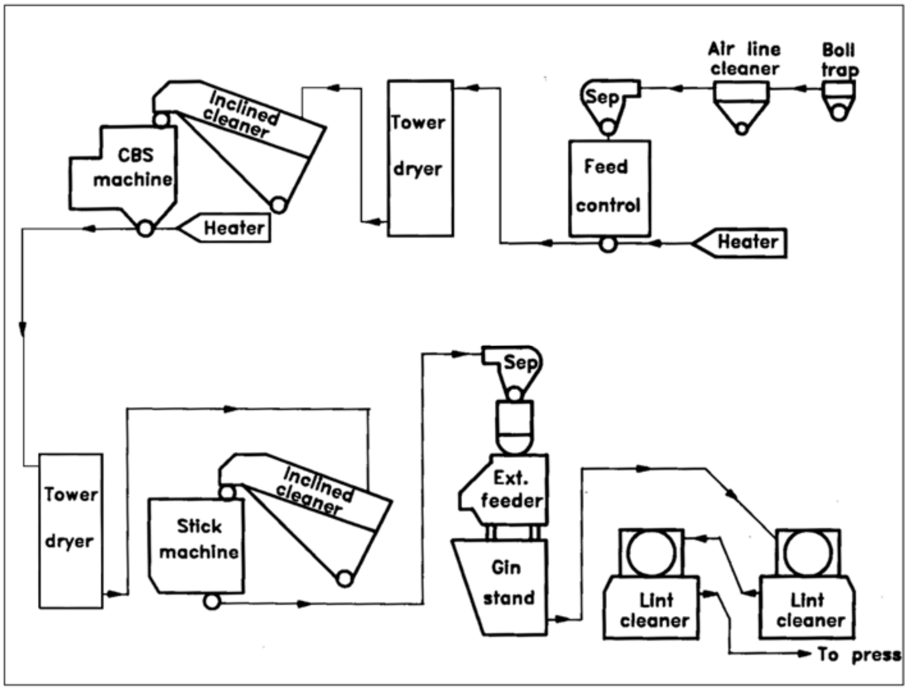
Table 5. Typical trash levels for picked and stripped cotton (Baker et al., 1994).

Type of Trash	Picked (kg [lbs])	Stripped (kg [lbs])
Burs	15 (34)	204 (450)
Sticks	4 (9)	52 (115)
Fine Trash	12 (26)	50 (110)
Motes	14 (30)	11 (25)
Total	**45 (99)**	**318 (700)**

The ginning process typically begins with dispersal of a seed cotton module. After the module is dispersed and seed cotton fed into the gin, the ideal moisture content for seed cotton cleaning is around $5\%_{wb}$ (Hughs et al., 1994). Heated air is typically used to lower seed cotton moisture in a dryer. Fiber strength is affected by moisture content; fibers at 15% moisture content are 1.7 times stronger than fibers at 4% moisture content (Moore and Griffin, 1964). To prevent fiber breakage during ginning and lint cleaning, the ideal moisture content of seed cotton at the gin stand is 6 to $7\%_{wb}$ (Mayfield et al., 1994). Furthermore, the force required to compress lint in the bale press increases exponentially as moisture content decreases (Anthony et al., 1994a). Moisture may be added back to seed cotton before the extractor feeder and/or lint slide with atomizing water sprays or humid air.



(a)



(b)

Figure 9. Example of typical machinery sequences for modern saw gins processing upland a.) picked and b.) stripped cotton (Anthony et al., 1994b; Baker, 1994).

Anthony and Eckley (1994) reported that gins typically use 40 to 60 kW-h of electricity per bale, and that electricity consumption per bale has remained steady since 1962. Hughs et al. (1994) suggested that a gin would use approximately 320 MJ/bale (300,000 BTU/bale) worth of natural gas or commercial propane in moisture control processes. While neither Anthony and Eckley (1994) nor Hughs et al. (1994) suggested differences in energy use between gins processing picked and stripped cotton, it is reasonable to assume that more gas and electricity would be consumed when processing more material at a gin.

The cost to the producer of ginning seed cotton varies between gins and by year but is often a function of the mass of seed cotton processed. Therefore, producers may expect to pay less per bale of lint for picked seed cotton compared to stripped seed cotton. Gins may also be able to recognize substantial savings in utility and maintenance costs by using less cleaning machinery and less heat for drying on picked cotton versus cotton harvested with a stripper. Based on the fee structure of the gin, these savings may or may not be passed on to the producer, but differences in ginning costs may represent an important input into any decision matrix used to compare harvester options. The cost of module transportation is often included in the cost of ginning, as well. Total transportation costs may be affected by the method of harvest as increased foreign matter content in seed cotton results in more modules that must be moved to the gin.

The objective of this study was to compare the cost of transporting and ginning seed cotton harvested with picker harvesters and stripper harvesters with and without field cleaners. Comparisons between harvest systems were made based on differences in foreign matter content of seed cotton, turnout, energy consumption at the gin, and the cost of ginning to the producer.

METHODS

Foreign Matter Content

At Sites 1, 3, and 4, 1.0 kg samples for fractionation analysis were collected from the weigh wagon for each replication of each harvest-method-by-variety combination.

For each sample, foreign matter in the seed cotton was determined by the Pneumatic Fractionator Method described by Shepherd (1972). Large foreign matter was removed from the samples by hand before fractionation and was categorized into burrs, sticks, and other. The mass of the entire sample and those of each fraction of foreign matter were determined with an Ohaus scale (Model CT1200-S, Florham Park, NJ) with a 0.1 g resolution. An analysis of variance test was conducted on the percent composition of samples from each treatment with the General Linear Model function in SPSS (SPSS 14.0; SPSS, Inc.; Chicago, Ill.) with the null hypothesis ($\alpha = 0.05$) that the percentages of total foreign material, hulls, sticks, leaf, pin trash, and motes between treatments were equal. Means were compared with the Least Significant Difference (LSD) pair-wise multiple comparison test.

Turnout

Turnout is a measure of the mass of marketable lint per unit mass of seed cotton entering the gin. Turnout is a function of the foreign matter content of seed cotton, the number of stages of cleaning, and variety (which primarily affects the mass of seed per unit mass of lint). Williford et al. (1994) reported that turnout for picked cotton is around 33% while turnout for stripped cotton typically ranges from 15 to 26%. In 2006, turnout for seed cotton from each harvest method at Site 1 was measured from the full-size modules ginned at New-Tex gin in Plains, Texas. Because only one module was produced with each harvest method, no statistical analysis was conducted on 2006 turnout data. In 2007, lint and seed turnout were measured from the samples ginned at the USDA-ARS Cotton Production and Processing Research Unit. An analysis of variance test was conducted on the lint turnout, seed turnout, and average seed weight per bale of samples from Sites 3 and 4 with the General Linear Model function in SPSS with the null hypothesis ($\alpha = 0.05$) that means between all samples were equal. Means were compared with the Least Significant Difference (LSD) pair-wise multiple comparison test.

Energy Consumption

Electricity and natural gas consumption were monitored for each module ginned at New-Tex Gin in 2006. Due to rainfall late in the season, two stages of lint cleaning were used to remove leaf from both picked and stripped seed cotton. Again, because only one module was produced with each harvest method, no statistical analysis was conducted on energy consumption data. In 2007, all samples were ginned at the USDA-ARS Cotton Production and Processing Research Unit gin in Lubbock, Texas. Lot sizes were too small to successfully measure utility consumption during ginning of each sample.

Cost to Producer

The cost of ginning varies from gin to gin and from year to year. At many gins, costs are a function of the mass of seed cotton processed. Various other costs such as module transport costs, bagging and tie charges, and classing fees may be included as well. In this study, the fee schedules for ginning at several gins were compared and the cost of ginning to the producer was analyzed as a function of harvest method.

RESULTS AND DISCUSSION

Foreign Matter Content

A MANOVA test using Wilk's Lambda ($n = 60$) revealed significant differences in foreign matter content and composition as a function of location ($p = 0.018$), variety ($p = 0.011$), harvest treatment ($p < 0.0005$), and interactions of location and treatment ($p < 0.0005$). Response variables differing significantly by location include sticks, grass, leaf, and pin trash. Response variables differing significantly by variety include sticks and pin trash. Response variables differing significantly by location-treatment interaction include burrs and pin trash. The composition of seed cotton from each harvest treatment is shown in table 6.

Table 6. Percent composition of harvested seed cotton.[a]

	Picked	Stripped with FC	Stripped without FC
Burs	1.8x	9.1y	19.9z
Sticks	0.6x	2.9y	2.0z
Leaf	1.7x	3.6y	3.6y
Pin Trash	0.8x	1.2y	0.3z
Motes	0.01x	0.01x	0.02x
Total Foreign Matter[b]	5.0 x	17.0 y	25.8 z

[a] No significant differences were detected ($\alpha = 0.05$) between means in the same row followed by the same letter.

[b] The data in this table are from grab samples of seed cotton and may not be representative of the mass of foreign matter that would be removed from seed cotton at t commercial gin.

The percent of burs ($p<0.0005$) and total foreign matter ($p<0.0005$) was higher for the stripper without field cleaner than the stripper with field cleaner. The amount of foreign material of all classes, with the exception of pin trash and motes, was higher for the stripper without the field cleaner than the spindle picker ($p < 0.0005$ in all cases). Spindle picked seed cotton had a lower percentage of total foreign material, burs, sticks, and leaf than the seed cotton that was stripped-and-field-cleaned ($p < 0.0005$ in all cases).

The fraction of picked seed cotton comprised of burs and sticks compares well to the fractions reported by Baker et al. (1994) (table 5), while the percentages of pin trash, motes, and total foreign matter reported by Baker et al. (1994) are above the 90% confidence interval of measured data. Similarly, for non-field-cleaned stripped cotton, the fraction of burrs compares well with the fraction reported by Baker et al. (1994), but the reported composition of all other components is above the 90% confidence interval for measured data.

Turnout

Lint turnout values for the modules from Site 1 ginned at a commercial gin are shown in table 7. Due to lack of independent samples, no statistical analysis was performed on data from Site 1.

Table 7. Turnout of modules from Site 1.

Treatment	Lint Turnout (%)
Picked	35.6
Stripped w/ Field Cleaner	30.2
Stripped w/o Field Cleaner	26.6

Significant differences were detected in lint turnout from cotton harvested at Sites 3 and 4 by variety ($p < 0.0005$), treatment ($p < 0.0005$), and the interaction between location and treatment ($p = 0.004$). The average lint turnout for each variety and harvest treatment for Sites 3 and 4 is shown in table 8 ($n = 6$ for each variety x treatment mean). For each variety, the lint turnout of stripped cotton was significantly lower than the lint turnout for picked samples. The higher turnout values for picked cotton indicate that less raw seed cotton is required to capture the lint and seed from a field, thus requiring fewer modules and lower energy inputs to process the cotton which will reduce transportation and ginning costs to the gin and may reduce costs to the producer.

Table 8. Turnout from Sites 3 and 4.[a]

Variety	Lint Turnout (%)		
	Picked	Stripped	Average
FM 9058 F	38.4 a	31.5 a	34.9 a
FM 9063 B2RF	35.4 b	29.8 a,b	32.6 b
PHY 485 WRF	32.7 c	27.7 c	30.2 c
ST 4554 B2RF	35.1 b	29.6 b	32.4 b
Average	**35.4**	**29.7**	**32.5**

[a] No significant differences were detected ($\alpha = 0.05$) between means in the same column followed by the same letter. Significant differences were detected between treatments for all varieties.

For all sites, turnout for both the picked and the non-field-cleaned cotton was slightly higher than predicted by Williford et al. (1994).

Seed turnout varied by harvest treatment ($p < 0.0005$) and location-treatment interaction ($p = 0.030$). The average seed turnout for picked samples was 54.6% compared to 45.8% from stripped samples. The average weight of seed per 220 kg (480 lbs) bale varied significantly ($p < 0.0005$; $n = 12$) by variety only (table 9). The variation in seed weight per bale explains the differences in lint turnout as function of variety for a given harvest treatment.

Table 9. Average seed weight per 220 kg (480 lbs) bale.[a]

Variety	Seed Weight per Bale (kg [lbs])
FM 9058 F	312 (688) a
FM 9063 B2RF	342 (754) b
PHY 485 WRF	352 (777) c
ST 4554 B2RF	340 (749) b

[a] No significant differences were detected ($\alpha = 0.05$) between means followed by the same letter.

Energy Consumption

Energy consumption during ginning for the modules from Site 1 ginned at a commercial gin is shown in table 10.

Table 10. Energy consumption for modules from Site 1.

Treatment	Electrical Consumption (kW-h/bale)	Natural Gas Consumption (MJ/bale [BTU/bale])
Picked	44.6	133 (126,000)
Stripped w/ Field Cleaner	47.6	152 (144,000)
Stripped w/o Field Cleaner	59.4	161 (153,000)

Energy consumption at the gin increased as the amount of foreign material in the seed cotton increased. Electrical consumption for all harvest methods was within the range predicted by Anthony and Eckley (1994). Natural gas consumption was less than half of that predicted by Hughs et al. (1994). Low gas consumption is likely due to the arid climate in the area where the cotton was harvested and the timeliness with which modules were ginned, preventing moisture increase in the modules due to precipitation.

Again, lower energy inputs to process picked cotton versus stripped cotton will reduce costs to the gin and may reduce costs to the producer.

Cost to Producer

The ginning schedules for the 2007-2008 crop for three commercial gins where cotton from all sites was ginned are shown in table 11. The estimated cost per bale for a 10,000 kg (22,000 lbs) module assuming average turnouts from table 8 are also shown. Producers at Sites 1 and 2 both use the same gin.

Table 11. Ginning schedules for 2007-2008 crop for commercial gins on the High Plains.

Gin	Ginning[a] ($/Mg [$/cwt])	Bag and Tie ($/bale)	Classing ($/bale)	Mod. Trans. ($/module)	Cost per Bale for Picked Module[b]	Cost per Bale for Stripped Module[c]
1	$55.06 ($2.50)	N/A	N/A	$50	$37.50	$42.86
2	$41.85 ($1.90)	$17.00	$1.80	N/A	$44.93	$48.66
3	$58.47 ($2.65)	N/A	N/A	N/A	$36.44	$41.64

[a] Cost per unit seed cotton; cwt = 100 lbs.

[b] Assuming 35.4% turnout.

[c] Assuming 29.7% turnout.

In all cases, the average cost of ginning per bale is greater for stripped-and-field-cleaned cotton than for picked cotton. On average, it cost the producer $4.76 per bale more to gin stripped-and-field-cleaned cotton versus picked cotton, giving a cost advantage to producers that pick their cotton over those that strip.

CONCLUSIONS

The cost of ginning cotton harvested with picker harvesters, stripper harvesters with field cleaners, and stripper harvesters without field cleaners was compared on the basis of foreign matter content, turnout, energy consumption during ginning, and cost to the producer. Picker harvested cotton had less burs, sticks, and leaf than stripped-and-field-cleaned cotton. The reduced foreign matter content in the picked cotton led to greater turnout, lower energy consumption during ginning, and a lower overall cost to the producer for module transportation and ginning.

CHAPTER V
FIBER QUALITY

INTRODUCTION

The quality of cotton fibers is dependent on many factors, including genetics, environmental conditions during production, and handling during harvest and processing. A number of fiber quality parameters influence the quality of yarn and fabrics produced from raw fibers and, therefore, the price that consumers are willing to pay for those fibers. Fiber length, strength, tenacity, maturity, fineness, and uniformity are among the properties that affect the way in which bundles of fibers will perform in spinning. Fiber maturity, diameter, color, reflectance, the presence or foreign matter, seed-coat fragments, and neps (entanglements in fibers) all affect the way a fabric absorbs dye and, therefore, the quality of the finished product.

HVI

The High Volume Instrument (HVI) system is the suite of instruments used by the USDA Agricultural Marketing Service (AMS) to class US cotton for marketing according to quality indicators. HVIs characterize fiber qualities by analyzing a sample of fibers. Fiber quality parameters reported by HVI include micronaire, length, length uniformity, strength, elongation, reflectance, yellowness, and trash.

Micronaire

Micronaire is a measure of fiber fineness and maturity. The definition of fiber fineness (Pierce and Lord, 1939) is given in eq. 2:

$$H = 1.52 A_w = 1.52 T(P - \pi T) \tag{2}$$

where: H = fineness (mtex),

A_w = wall area (μm^2),

T = wall thickness (μm), and
P = perimeter (μm).

Maturity refers to the degree of thickening of the fiber secondary wall (Pierce and Lord, 1939). When a cotton fiber is developing, it is a round, hollow tube. As the fiber matures, cellulose is deposited on the inside of the tube, thickening the cell wall. When fibers begin to desiccate, the tube collapses and becomes “kidney-shaped” with a hollow center (lumen) (fig. 10), and the fiber twists.

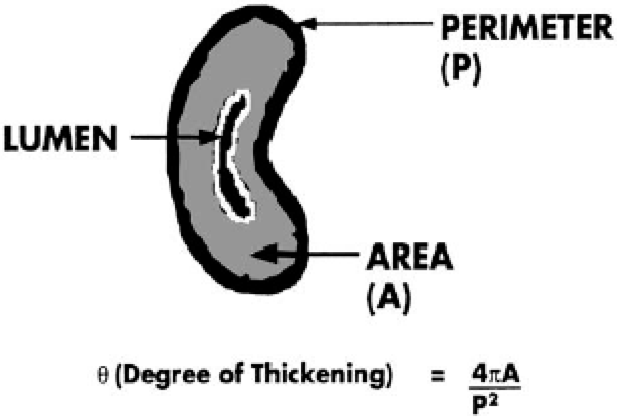


Figure 10. Cross-section of cotton fiber (Uster Technologies, 2004).

The more mature a fiber is, the more convolutions will form during desiccation (fig. 11). A fiber is considered immature if the cell wall accounts for less than 25% of the cross-sectional area of the fiber (Pierce and Lord, 1939).

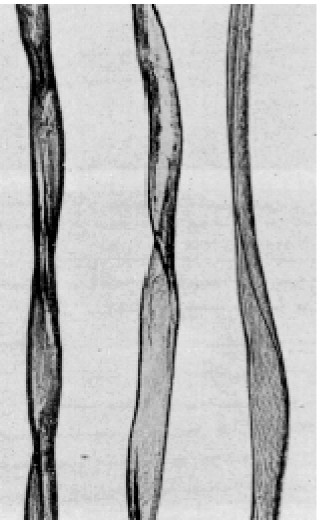


Figure 11. Cotton fibers of varying maturity: the fiber on the left is "fully mature," the one in the center is immature, and the one on the right is dead (Uster Technologies, 2004).

The classical definition of maturity (Pierce and Lord, 1939) is given in eq. 3:

$$M = \frac{\theta}{0.577} = \frac{4\pi A_w}{0.677P^2} = \frac{4\pi T(P - \pi T)}{0.577P^2} \tag{3}$$

where: M = maturity ratio,

θ = degree of thickening,

A_w = wall area (μm^2),

T = wall thickness (μm), and

P = perimeter (μm).

Circularity is the ratio of the cross-sectional area of a fiber to the area of a circle having the same perimeter. The maturity ratio (M) is the ratio of the number of fibers with circularity values greater than 0.5 to the number of fibers with circularity values below 0.25. The degree of thickening (θ) is calculated as the ratio of the cross-sectional area of a fiber to the area of a circle having the same perimeter as the fiber (Pierce and Lord, 1939).

Lord (1956) determined that resistance to airflow through a randomly oriented plug of fibers was related to fineness and maturity according to eq. 4:

$$HM = 3.86MIC^{2} + 18.16MIC + 13 \tag{4}$$

where: H = fineness (mtex),

M = maturity ratio, and

MIC = measured micronaire.

To measure micronaire with the HVI, approximately 10 g of randomly oriented fibers are placed in a chamber and compressed to a fixed volume. Air is passed through the sample, and micronaire is determined based on the permeability of the sample. The relationship between micronaire and market value is shown in fig. 12 (adapted from USDA-AMS, 2001).

Figure 12. Relationship between micronaire and market value (adapted from USDA-AMS, 2001).

Micronaire alone cannot characterize fiber fineness or maturity. Fiber fineness is an indicator of the fiber circumference and is predominately affected by variety. Fiber maturity is an indicator of the portion of the fiber cross section that has been filled with cellulose. All else being equal, the finer the fibers, the less permeable a sample of given mass will be, and the lower the micronaire reading. However, the less mature the fibers, the more fibers will be in a sample of a given mass and, therefore, the less permeable the sample. Therefore, a sample of fine, immature fibers could have the same micronaire value as a sample of coarse, mature fibers.

Length

The HVI measures fiber length and length uniformity by measuring light penetration through combed beards of fibers. Two 10 g samples are placed in the HVI and subsamples of lint fibers are grasped on one end by a clamp. The instrument then combs the clamped fibers to orient them parallel to one another and straighten them, thus forming fiber beards. Light is passed through both beards, and the variation in light penetration across each fiber beard is used to estimate the length of all fibers within both beards. The average length of the longest one-half of fibers (upper-half mean length or UHML) is reported.

Length uniformity is the ratio between the mean length of all the fibers and the UHML and is expressed as a percentage. Ramey and Beaton (1989) reported a negative correlation between short fiber content and HVI length uniformity and concluded that the HVI uniformity index can be used to predict some aspects of a cotton's performance in spinning. Table 12 shows typical ranges of length uniformity (USDA-AMS, 2001).

Table 12. Length uniformity (USDA-AMS, 2001).

Degree of Uniformity	HVI Uniformity Index (%)
Very High	Above 85
High	83-85
Intermediate	80-82
Low	77-79
Very Low	Below 77

Strength and Elongation

After measuring length and length uniformity, the strength and elongation of fibers in the beard are measured. Each beard of fibers is clamped by a second jaw 3.18 mm (1/8 in.) from the first. The force required to break the beard is measured along with the distance the beard elongates before breaking. The mass of fibers broken is estimated by measuring the light attenuation of fibers from an array of red light-emitting diodes and adjusting for the micronaire of the sample (Keskin et al., 2001). Strength is reported in g/tex, where a tex is the mass (in grams) of 1,000 m of fiber. Elongation is reported as a percent of the original gauge length. Table 13 shows typical degrees of strength for cotton fiber bundles (USDA-AMS, 2001).

Table 13. Fiber strength (USDA-AMS, 2001).

Degree of Strength	HVI Strength (g/tex)
Very Strong	Above 30
Strong	29-30
Average	26-28
Intermediate	24-25
Weak	Below 24

Color and Trash

HVI measures the reflectance (Rd), yellowness (+b), and trash content of a sample by analyzing two pictures of the sample. The reflectance and yellowness of a cotton affects its ability to absorb dye, and degraded color may be indicative of weathered cotton that will not process well. The trash content of cotton affects the efficiency with which a bale can be processed. Bragg et al. (1995) found that increased bark concentrations did not significantly reduce the quality of yarn produced with an older rotor-spinning frame, but the number of yarn breaks during spinning increased approximately 66% for each one percent increase in bark content, thus reducing the efficiency with which barky cottons may be spun. No effect was seen on yarn quality or processing efficiency when modern textile processing equipment was used. Bargeron et al. (1988) reported that grass contamination in cotton increased ends down and decreased yarn strength when cotton is ring-spun.

The trash content is determined by measuring the portion of the sample surface area that is occupied by non-lint material, as observed in the pictures of the sample. While the HVI trash content analysis has been demonstrated to measure false positives when shadows appear on the HVI scan, reasonable correlations have been made between HVI trash measurements and classer leaf grades (USDA-AMS, 2001).

AFIS

Unlike the HVI, which estimates fiber properties from a bundle of fibers, the Advanced Fiber Information System (AFIS) measures properties of individual fibers. For each replication, a 0.5 g sample is formed into a 30 cm long sliver and placed in the sampling tube of the AFIS. A mini-card separates individual fibers, which then pass through two optical sensors: one for trash, neps, and dust and the other for length and maturity. The entire sample is analyzed for trash, neps, and dust while only 3,000 fibers are analyzed for length and maturity.

Nep Classification

Neps are bundles of fibers that are entangled together and can lead to blemishes in fabrics, especially in fabrics made from ring-spun yarns (Gupta and Vijayshankar, 1985). Neps result in greater waste during processing and may lead to imperfections in yarns and fabrics. Fiber neps may occur naturally in the boll, but nep counts are increased by mechanical processing of fibers. Seed-coat neps are fragments of cottonseed that still have fibers attached to them. Seed-coat neps account for a large portion of imperfections in coarse yarns but contribute less to imperfections in finer yarns. This variation in the contribution of seed-coat neps to yarn neps may be the result of fewer seed-coat neps per mass of cotton in longer staple cottons as are used in the production of fine yarns, or it may be the result of increased detection of small, fibrous neps in finer yarns that escape detection in coarser yarns (Gupta and Vijayshankar, 1985). Table 14 contains general ranges for nep counts in raw upland cotton (Uster Technologies, 2004).

Table 14. Nep counts (Uster Technologies, 2004).

Description	Neps/g
Very High	Above 451
High	301-450
Medium	201-300
Low	101-200
Very Low	Below 101

AFIS provides counts and sizes for fiber and seed-coat neps, using differences in electrical wave forms from fibers, fiber clumps, and seed coats to differentiate among the classes of neps.

Length

The length of each individual fiber measured by the AFIS is recorded so that a fiber length distribution can be determined. Fiber length is estimated by measuring the length of time it takes for a given fiber to pass through the optical sensors at a known speed. This length is likely slightly underestimated due to unaccounted-for crimp in individual fibers. AFIS reports a mean length of fibers by weight and number, the coefficient of variation for length measurements, the upper quartile length (UQL or average length of the longest 25% of fibers), and short fiber content (SFC) (i.e. fibers shorter than 1.27 cm [0.5 in]). Table 15 contains general ranges for SFC in raw upland cotton (Uster Technologies, 2004).

Table 15. Short fiber content (Uster Technologies, 2004).

Description	SFC by Number (%)	SFC by Weight (%)
Very High	Above 33	Above 14
High	29-33	12-14
Medium	24-28	9-11
Low	19-23	6-8
Very Low	Below 19	Below 6

Maturity and Fineness

AFIS estimates fiber maturity and fineness by analyzing the shape of individual fibers with the two optical sensors. The sensors indirectly measure the shape of each fiber by determining the variations in light attenuation from two different angles as a fiber passes through the sensing point in orer to determine the input variables to eq. 3. AFIS reports the maturity ratio and the immature fiber content (IFC) of samples. Table 16 contains general ranges for maturity ratios and IFC in raw upland cotton (Uster Technologies, 2004).

Table 16. Maturity data (Uster Technologies, 2004).

Description	Maturity Ratio	Immature Fiber Content (%)
Very High	Above 0.95	Above 14
High	0.91-0.95	12-14
Medium	0.86-0.90	9-11
Low	0.76-0.85	6-8
Very Low	Below 0.76	Below 6

Fineness algorithms were originally determined by comparing results from AFIS optical sensors to cotton fibers analyzed by a cut-and-weigh method (Uster Technologies, 2004).

Montalvo et al. (2007) found that that the AFIS-PRO system had a very narrow dynamic range within which reported fineness and maturity measurements are unbiased.

The authors found that fineness and maturity values reported by the AFIS-PRO system were unbiased when the sample micronaire was equal to 3.8. As micronaire values decreased below 3.8, the magnitude of negative bias in fineness and maturity values increased. As sample micronaire values increased above 3.8, the magnitude of positive bias in fineness and maturity values increased. Because, the AFIS system does not consistently assess fiber fineness and maturity across cottons withg varying micronaire values, the magnitude of the measurement bias should be accounted for when comparing the fineness and maturity of cottons with varying values of micronaire.

Trash Content

The trash content of a sample is measured by passing all of the fibers from the sample sliver through an optical sensing point following the mini card. AFIS reports dust count and size, trash count and size, and percent visible foreign matter. According to the International Textile Manufacturers Federation (ITMF), dust is foreign matter smaller than 500 µm while trash is foreign matter larger than 500 µm.

Previous Research

While research has been conducted to compare fiber quality between stripper and picker harvested cotton, most of this research focused on lower yielding stands of cotton and used harvest machinery that was not representative of modern harvest systems. Furthermore, fiber quality traits are not always sufficient to indicate spinning performance and yarn quality, especially if the only fiber quality traits analyzed are those indicated by the current USDA cotton classing system.

Comparing fiber quality between picker and stripper harvested cottons, Brashears and Hake (1995) found better leaf grades in Paymaster HS26 harvested with a picker harvester versus a stripper harvester with and without field cleaning, but there was no difference in leaf grade between the harvest treatments for Stoneville 132. The authors did not suggest a reason for the differences between varieities. No significant effects were seen in HVI staple length, micronaire, strength, or length uniformity between harvest methods. The two-row picker used by Brashears and Hake (1995) does not reflect the advances in technology of modern harvest machinery, making application of this study to modern production systems questionable.

Vories and Bonner (1995) compared fiber quality between stripped (with field cleaning) and picked dryland cotton in Arkansas. None of the HVI parameters were significantly different between harvest methods. In 1992, when weather conditions were more harsh, fiber quality indices were better for picker harvested cotton than for stripper harvested cotton, confirming the finding of Kerby et al. (1986) that grade differences between harvest methods are most pronounced during years of adverse conditions. Though not significantly different, micronaire values for stripped cotton were lower than those of picked cotton for two of the three years of the study. Again, the brush stripper used in the Vories and Bonner (1995) study (an Allis Chalmers 880 with alternating brushes and flaps) does not represent modern harvesting machinery, making extrapolation of these results to modern production systems tenuous.

Baker and Brashears (2000) evaluated the effect of field cleaners on fiber and yarn quality of three stripper varieties of cotton. They found that field cleaners reduced lint trash content at each stage of lint cleaning, thus resulting in somewhat better color and leaf grades. Half of the samples analyzed indicated a one leaf grade improvement from use of a field cleaner. Field-cleaned cotton also had higher micronaire and maturity ratios and reduced nep counts in fiber and yarn.

Brashears and Baker (2000) compared the quality of two varieties of cotton harvested with a finger stripper, a brush roll stripper (both with field cleaners), and a spindle picker. Leaf grades were similar for Paymaster 2200 regardless of harvest method, while the leaf grade for picker harvested Delta and Pine Land (D&PL) 1220 was significantly lower for the same variety harvested with both strippers. For both varieties, the fiber length of picked cotton was longer and the micronaire was higher than that of the same variety that was stripped. Fiber length of brush stripped cotton was also significantly longer than finger stripped cotton. For both varieties, nep counts were significantly lower for the picker harvested cotton than for the stripped cotton.

Willcutt et al. (2002) compared lint quality as affected by harvester type for picker varieties grown on the Mississippi delta. They observed better values in nep counts, short fiber content by weight, visible foreign matter and immature fiber content for picked cotton than stripped cotton samples. Classer staple, HVI length, uniformity, and strength were not affected significantly by harvest method.

Faircloth et al. (2004) evaluated turnout, fiber quality, and loan value from cotton harvested with brush strippers versus spindle harvesters in northeast Louisiana. Yields in this study ranged from 3.04 to 6.67 bales/ha (1.23 to 2.70 bales/ac assuming 220 kg [480 lbs] bales). Few statistically significant differences in fiber quality from the two harvesting treatments were observed, but trends of decreased micronaire and increased color grade in stripper harvested cotton were seen. The varieties used in the study are not representative of those used on the High Plains and make extrapolation to this region troublesome.

McAlister and Rogers (2005) investigated the effect of harvesting method on fiber and yarn quality from Ultra-Narrow-Row cotton grown in South Carolina. The authors reported increased micronaire, strength, UHML, and length uniformity and decreased yellowness in picked samples versus stripped samples. AFIS results showed that picked samples has fewer short fibers and neps; less dust, trash, and visible foreign matter; was more mature; and was less fine than stripped samples. However, the samples analyzed in this study were not harvested until after Christmas due to extremely wet weather during the harvest season. Due to varietal differences, the use of Ultra-Narrow-Row cotton, and the extreme weathering of the cotton before harvest, the applicability of the results of this study to the High Plains is questionable. However, the protocols for fiber and yarn testing employed in the McAlister and Rogers study are helpful in determining the effect of harvesting method throughout the processing chain.

The objective of this research was to examine the effects of harvest method on fiber quality from irrigated cotton harvested on the High Plains of Texas with modern harvest equipment. Fiber quality parameters were measured with HVI and AFIS. This study represents the first commercial-scale harvester comparison project conducted in the High Plains region.

METHODS

Irrigated cotton was harvested from commercial farms on the High Plains of Texas in 2006 and 2007. In 2006, Stoneville 4554 B2RF was harvested from Site 1 in late October/early November with a six-row John Deere 9996 spindle picker with Pro-16 row units equipped with scrapping plates on the front and rear drums, a six-row John Deere 7460 stripper harvester with field cleaner, and the same stripper harvester bypassing the field cleaner. A 140 kg sample of seed cotton was collected from each plot (four per harvest treatment) and placed in bulk seed bags for ginning.

In 2007, FM 9058 F, FM 9063 B2RF, PHY 485 WRF, and ST 4554 B2RF were harvested from Sites 3 and 4 with a six-row John Deere 9996 spindle picker with Pro-16 row units equipped with scrapping plates on the front drums and a six-row John Deere 7460 stripper harvester with field cleaner. A 140 kg sample of seed cotton was collected from each plot (three per harvest treatment per variety per location) and placed in bulk seed bags for ginning. At all sites, defoliation and harvest aid treatments were identical for both picked and stripped cotton based on the producer's observations of harvest readiness.

Samples were ginned at the USDA-ARS Cotton Production and Processing Research Unit in Lubbock, Texas, on a commercial-scale gin. In both 2006 and 2007, two stages of seed cotton cleaning were used. Each stage included a tower dryer, stick machine, and a six-cylinder incline cleaner. The gin stand was a Continental Double Eagle saw-type gin stand. Due to late season rains in 2006, the leaf trash was difficult to separate so two stages of lint cleaning were used on all samples. Samples were collected for HVI and AFIS measurements after one and two stages of lint cleaning to determine if interactions were present between harvest method and lint cleaning. In 2007, only one stage of lint cleaning was used.

Lint samples were conditioned at 65% RH ± 2% and 21^{o}C ± 1 (according to ASTM D1776-04 Standard Practice for Conditioning of Textiles) for fiber quality analysis and tested with an HVI (Model 900A; USTER®; Uster, Switzerland) with four micronaire readings, four color readings, and ten length and strength readings per sample, and the AFIS with five replications of 3,000 fibers tested per sample at the International Textile Center in Lubbock, Texas.

All treatment means from fiber quality tests were compared with the General Linear Model function in SPSS (SPSS 14.0; SPSS, Inc.; Chicago, IL). A MANOVA test was conducted to determine overall differences between harvest treatments before conducting pair-wise comparisons. The null hypothesis tested in all cases was that means in each harvest treatment were equal. Means were compared with the Least Significant Difference (LSD) pair-wise multiple comparison test. Two sample Kolmogorov-Smirnov tests were used to compare fiber length distributions between harvest treatments. A 0.05 level of significance was used in all tests except where noted differently.

RESULTS AND DISCUSSION

Because samples collected in 2007 were substantially more mature than samples collected in 2006, the results from each year are presented separately.

2006

The results from HVI and selected parameters from AFIS testing from samples collected in 2006 are shown in tables 17 and 18, respectively. Caution should be used when interpreting results because fiber maturity for all samples was low, which may exacerbate differences in fiber quality parameters as a function of harvest treatment because the thin secondary wall of the fibers may lead to lower fiber strength and elongation. Results of MANOVA analyses (n = 4 for each treatment) indicated that overall treatment differences were not detected for HVI results at 95% confidence level, so the results of pair-wise comparisons of HVI data should be analyzed cautiously.

Treatment differences were detected by MANOVA when analyzing results of AFIS tests (p<0.0005 using Wilk's Lambda).

Table 17. Results from 2006 HVI analysis.[a]

	Picked	Stripped with FC	Stripped without FC
Micronaire	3.5x	3.2y	3.2y
Length (cm [in.])	2.82 (1.11)x	2.77 (1.09)y	2.79 (1.10)x,y
Uniformity (%)	80.4x	79.4y	79.2y
Strength (g/tex)	27.1x	26.2x	26.6x
Elongation (%)	8.4x	8.7x	8.5x
Reflectance (%)	81.6x	81.1x,y	80.9y
Yellowness	8.1x	8.5x,y	8.7y
Leaf	2.0x	2.5x	2.3x

[a] No significant differences were detected ($\alpha = 0.05$) between means in the same row followed by the same letter.

Table 18. Selected results from 2006 AFIS analysis.[a]

	Picked	Stripped with FC	Stripped without FC
Nep count (neps/g)	561x	661x,y	702y
Short fiber by weight (%)	16.1x	17.3x	17.7x
Visible foreign matter (%)	1.06x	1.18x	1.15x
Immature fiber content (%)	12.8x	13.7x	13.8x
Maturity ratio	0.78x	0.78x	0.77x

[a] No significant differences were detected ($\alpha = 0.05$) between means in the same row followed by the same letter.

Micronaire for spindle picked cotton was significantly higher than for either stripper treatment, confirming the results of Brashears and Baker (2000). Stripper harvesters tend to have higher harvesting efficiencies than pickers; however, the increase in lint fiber harvested is typically comprised of less mature fibers that therefore have lower micronaire values. Length uniformity was also significantly better for picked cotton versus both stripper treatments. Both micronaire and length uniformity values for picked cotton were within the base market value range, while both stripper treatments led to micronaire and length uniformities in the discount range. Unlike the results from

Baker and Brashears (2000) no differences were seen in fiber quality parameters between stripped cotton that was field-cleaned versus non-field-cleaned cotton.

Average AFIS length distributions by number for all treatments are shown in fig. 13. All length distributions are poor and skewed to the right due to the lack of maturity. Nevertheless, we can see that the fiber length distribution of the picked cotton is slightly better (less fiber fragments, less short fibers, and more of the longer fibers). Results of the Kolmogorov-Smirnov tests showed significant differences between the fiber length distributions of the picked samples and both stripped samples ($p < 0.01$), but no significant difference was detected between the fiber length distributions of the stripped samples with and without a field cleaner.

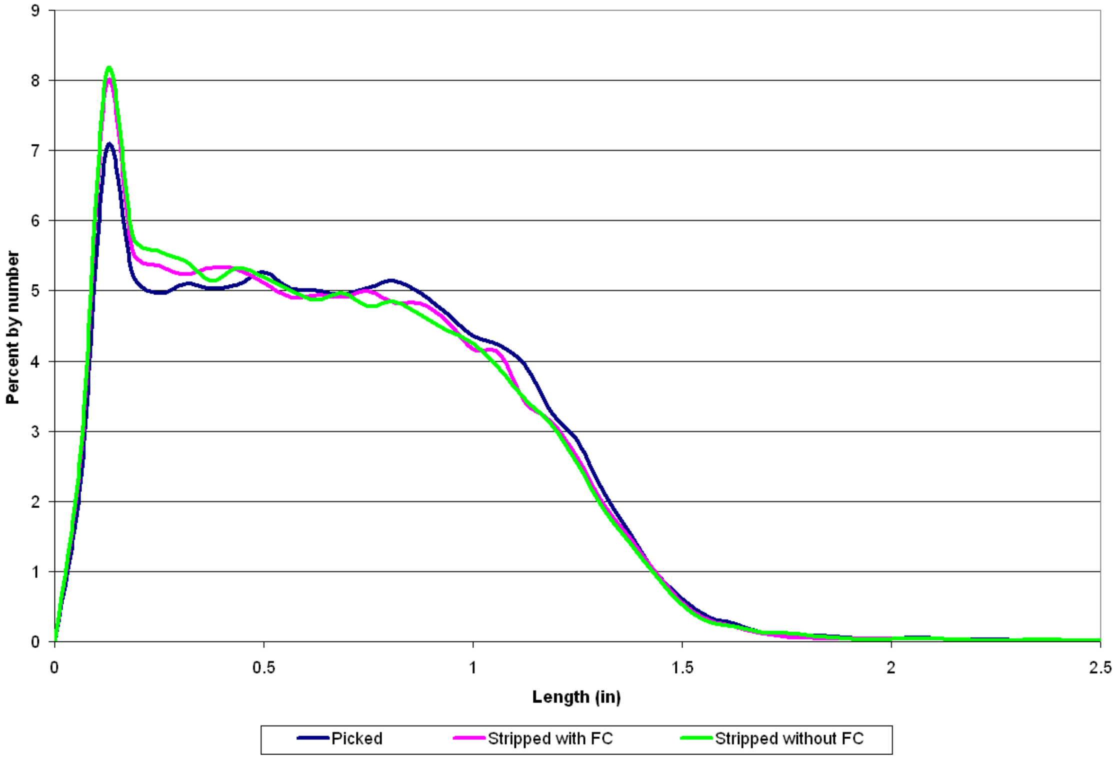


Figure 13. 2006 AFIS length distributions by number.

No significant interactions were detected between harvest treatment and lint cleaning for fiber quality parameters testing with HVI and AFIS. As expected, lint cleaning resulting in a greater reduction in visible foreign matter for both stripper treatments than for picked cotton. However, no differences were detected in the change in length, strength, nep count, nor nep size of fibers between harvest treatments suggesting that differences in fiber quality reported in tables 17 and 18 are the result of harvest treatment rather than interactions between harvest treatment and lint cleaning.

2007

The average results of HVI and selected parameters of AFIS testing from samples collected in 2007 are shown in tables 19 and 20, respectively. A MANOVA test using Wilk's Lambda revealed significant differences in HVI and AFIS results as a function of harvest location, variety, and treatment (all p-values < 0.0005; n = 24 for each treatment). Multivariate interactions were also significant between variety and location (p < 0.0005 for HVI; p = 0.008 for AFIS) as well as variety and harvest treatment (p = 0.036 for HVI; p = 0.043 for AFIS).

Table 19. ANOVA results from 2007 HVI analysis.[a]

	Picked	**Stripped with FC**	**Significant Variables**[b]
Micronaire	4.2x	4.0x	None
Length (cm [in.])	2.97 (1.17)x	2.95 (1.16)x	V, L, V*L
Uniformity (%)	82.1x	81.9x	V, L, V*L
Strength (g/tex)	29.3x	29.6x	V, L, V*L
Elongation (%)	8.7x	8.7x	V, L
Reflectance (%)	80.9x	79.9y	V, L, T, V*T
Yellowness	8.3x	8.6y	V, L, T
Leaf	1.3x	1.8y	V, T

[a] No significant differences were detected ($\alpha = 0.05$) between means in the same row followed by the same letter.

[b] V = variety; L = location; T = harvest treatment; V*L = variety-location interaction; V*T = variety-treatment interaction

While differences in treatment means were detected only in color and leaf grades, a paired-samples t-test ($\alpha = 0.05$) was conducted comparing differences in HVI parameter values between picked and stripped samples from the same plot to reduce varietal and location impacts. Results of the paired-samples t-test revealed significant improvements in micronaire, reflectance, yellowness, and leaf grade from picked samples versus stripped samples (table 21).

Table 20. Selected ANOVA results from 2007 AFIS analysis.[a]

	Picked	Stripped with FC	Significant Variables[b]
Nep count (neps/g)	310x	370y	V, L, T
Short fiber by weight (%)	10.3x	10.8y	V, L, T, V*L, V*T
Visible foreign matter (%)	1.46x	2.23y	V, T, V*T
Immature fiber content (%)	8.7x	9.5y	V, L, T, V*L
Maturity ratio	0.85x	0.84y	V, T

[a] No significant differences were detected (α = 0.05) between means in the same row followed by the same letter.

[b] V = variety; L = location; T = harvest treatment; V*L = variety-location interaction; V*T = variety-treatment interaction

Table 21. Selected paired sample t-test results from 2007 HVI analysis.

	Mean Difference[a]	p-value
Micronaire	0.1	0.001
Reflectance (%)	1.0	<0.0005
Yellowness	-0.3	<0.0005
Leaf	-0.5	0.005

[a] Mean difference = (Avg. of picked samples) – (Avg. of stripped samples).

Differences in micronaire values between harvest treatments were less pronounced in 2007 than 2006, but on average, fibers were more mature in 2007 due to better growing conditions, as can be seen by the more normal shape of the AFIS length distribution for FM 9058 from 2007 (fig. 14) compared to 2006 (fig. 13). These results confirm the conclusions of Kerby et al. (1986) that grade differences between harvest methods are more pronounced during years of adverse growing conditions. As with the results from Willcutt et al., (2002), significant differences were detected between harvest treatments in nep counts, short fiber content, and visible foreign matter in 2007, but nep counts and short fiber content were both reduced relative to 2006 values. Significant differences ($p < 0.01$ for all tests) were detected between the average fiber length distributions from each treatment for all varieties (see fig. 14 for example fiber length distributions from 2007). Overall, variety had a greater impact on fiber quality parameters than harvest treatment.

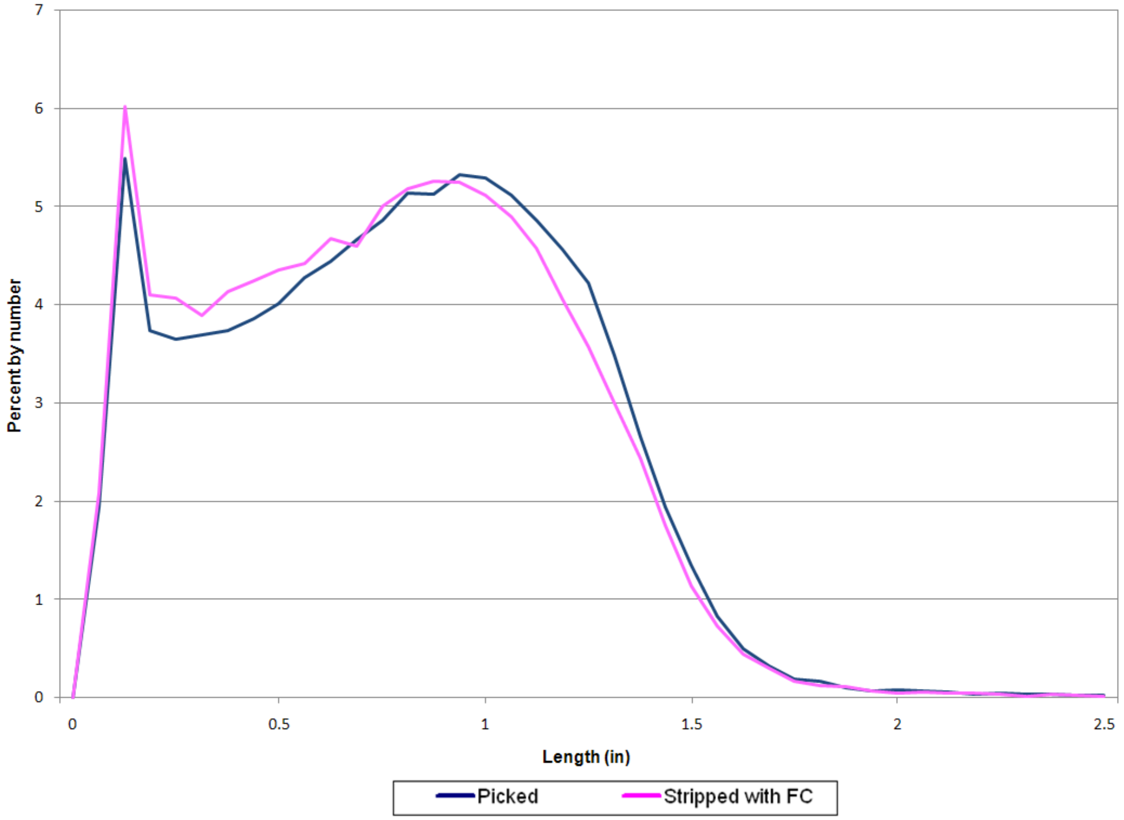


Figure 14. 2007 AFIS length distributions of FM 9058 F by number.

Differences in the quality of fibers as measured by the HVI led to significant differences in the value of lint by harvest treatment in 2006 but not in 2007 as indicated by the average loan values and West Texas spot prices (table 22; USDA-AMS, 2007).

Table 22. Average loan values and West Texas spot prices (USDA-AMS, 2007).[a]

	2006		2007	
	Loan ($/kg [$/lbs])	Spot Price ($/kg [$/lbs])	Loan ($/kg [$/lbs])	Spot Price ($/kg [$/lbs])
Picked	1.264 (0.5738)x	1.160 (0.5268)x	1.301 (0.5907)x	1.191 (0.5408)x
Stripped w/FC	1.167 (0.5300)y	1.104 (0.5014)y	1.288 (0.5849)x	1.187 (0.5390)x
Stripped w/o FC	1.165 (0.5291)y	1.087 (0.4934)y	--	--

[a] No significant differences were detected (α = 0.05) between means in the same column followed by the same letter.

No significant differences were detected the loan rates or spot prices between locations or varieties in 2007. The higher quality of picked cotton compared to stripped cotton from the same field led to higher average sale prices for picked cotton. The reduction in price for stripped cotton compared to picked cotton in both 2006 and 2007 was less severe than the reduction in loan value.

CONCLUSIONS

The effect of harvest treatment on fiber quality was compared for four varieties of cotton commonly grown on the High Plains of Texas. Fiber quality indices were determined with HVI and AFIS instruments and were compared for cotton harvested with a spindle picker, a brush-roll stripper with a field cleaner, and the same stripper harvester without a field cleaner (in 2006 only). Each year, all samples underwent similar cleaning regimes during ginning.

In 2006, micronaire, length, and length uniformity as measured by HVI were better for picker harvested cotton than for stripped cotton leading to a higher loan value and average sale price for the producer. In 2007, when growing conditions were better and fibers were more mature, differences in fiber quality parameters between picked and stripped cottons were less pronounced leading to less discrepancy in the value of cotton harvested. However, in 2007, differences in nep counts, short fiber content, and visible foreign matter between harvest treatments were distinguishable.

The results of this study indicate that producers may realize greater fiber quality and lint value by using picker harvesters, but the magnitude of those differences may be a function of growing conditions and/or fiber maturity. Varietal differences also played a large role in determining fiber properties, but in 2007, no differences were seen in the value of harvested lint as a result of these differences.

CHAPTER VI
YARN QUALITY

INTRODUCTION

The cotton producer’s final customer is the textile mill to which he sells his cotton. Textile mills vary in the type and quality of cotton they purchase based on the product they are producing. Higher quality textiles require longer, finer yarns with sufficient strength to endure spinning and weaving or knitting processes. Mills producing products such as denim or socks use lower quality cotton because it is less expensive yet still meets the requirements to produce goods that will satisfy their customers. Cottons of varying quality can also be blended together or with synthetic fibers to produce yarns of varying quality with characteristics desirable for specific applications.

The first stage of processing at a textile mill includes opening, cleaning, and blending. Bales are placed in a laydown room where layers are skimmed off and transported pneumatically to an opener. Opening involves gently separating masses of fibers to prepare them to feed into the carding machine. Partial cleaning may also occur in this step. Cotton or cotton blends are then placed into a feed control system that further reduces tuft size and regulates the flow of material to the carding machine.

The card cleans and parallelizes fibers for subsequent formation into yarn. Cleaning is conducted by either rotating licker-inns with pins or wire that remove foreign matter or by flats with increasingly densely packed wire located around the card cylinder to thin the fiber web and remove trash. The resulting web is then fed through a trumpet and condensed into a sliver of parallel fibers that are placed into cans.

Slivers formed by the card are then blended and drafted during breaker drawing. Multiple slivers are combined during this process to reduce variability in the final sliver. Fibers in the sliver are further parallelized, and the sliver density is made more uniform. Morton and Summers (1949 and 1950) demonstrated that the number of fiber hooks resulting from fiber crimp is reduced by drafting, up to three stages, at which point the majority of fibers have no hooks. Garde et al. (1961) demonstrated that “trailing hooks” are reduced during drafting more efficiently than “leading hooks.” Because the sliver is drafted in the direction that it is, breaker drawing removes “trailing hooks” on the fibers coming from the card web. The sliver resulting from breaker drawing is again placed in a can. For open-end spinning, drawing may be omitted and the slivers can be spun with no further pre-processing.

After breaker drawing, slivers that will not be combed proceed directly to finisher drawing. Slivers that will be combed are formed into a lap by blending multiple slivers and spreading them into a thin lap that is then combed to remove short fibers and residual foreign material. Between 10 and 15 percent of the material is removed as noils during the combing process (Werber and Backe, 1994). The slivers formed after combing then undergo finish drawing, which again blends, parallelizes, and evens the slivers, this time removing “leading hooks” resulting from fiber crimp.

The final step before ring spinning is roving. Roving involves further drafting the sliver to avoid exceeding the weight limits of the spinning frame during the spinning process. During roving, a slight twist is placed into the material before it is wound onto a bobbin to prevent breaking the roving as it is drawn into the spinning frame.

Most yarn is formed by either ring or open-end spinning methods. In ring spinning, roving is again drafted and then drawn through a traveler rotating around a bobbin which adds more twist to the resulting yarn. In open-end spinning, a sliver is fed into a rotating opener, where trash is removed and the sliver is drafted. In the rotor, which can spin at speeds exceeding 100,000 rpm, centrifugal force separates the fibers, which then align in the groove of the rotor. The resulting yarn is pulled out of the rotor chamber and wound onto a bobbin.

The performance of fibers during processing and spinning is dependent on several fiber properties. Fiber maturity and strength affect the fiber’s ability to withstand the forces placed upon fibers during drafting and spinning. Fiber length and fineness affect the forces between fibers that dictate the “count,” or fineness, of the final yarn. Foreign matter and neps lead to unevenness in yarns and may result in ends down, or breaks, during spinning that greatly reduce production efficiency or may lead to imperfections in fabrics.

The spinning limit (i.e. the maximum yarn count achievable) of a cotton is dependent on fiber properties and spinning method. Yarn count (Ne) is a measure of fineness indicating the number of 840 yd skeins that can be made from one pound of yarn (ASTM Standards, 2007). Longer, stronger fibers are better able to withstand the large forces placed on them during spinning and are therefore able to be spun into finer yarns. Müller (1991) reported that length distribution of fibers also significantly affects the spinning limit of a cotton. Typically, the minimum number of fibers in the cross-section of a commercial yarn is approximately 60 for carded, ring-spun yarns and 100 or more for carded, rotor-spun yarns (Steadman et al., 1989). Therefore, finer fibers are able to be spun into finer yarns as well.

While fiber length, strength, and fineness are most frequently correlated to yarn properties (Krifa et al., 2001), the trash content of cotton can also affect the maximum yarn count achievable without losing efficiency due to excessive ends down. Due to the high angular speeds encountered by fibers during spinning, trash particles can cause fiber breaks by exerting centrifugal force on the forming yarn, particularly during rotor spinning (Steadman et al., 1989). Finer yarns are particularly susceptible to end breaks due to the presence of trash in the roving.

Yarn Quality Indices

Count Strength Product

Count strength product (CSP), also known as skein-break factor, is a measure of yarn strength, and is calculated by multiplying the yarn count by the force required to break a yarn skein. El Mogahzy (1988) reported that skein break factor increased with increasing fiber length, length uniformity, and fiber strength but decreased with increasing reflectance (Rd) and fiber fineness. El Mogahzy et al. (1990) found similar results for a different set of cottons but did not find significant correlations between reflectance and CSP. Subramanian (2004) proposed a phenomenological model to predict CSP rather than one derived from multiple linear regression analysis. While the Subramanian (2004) model accounts for the mode of transfer of fiber tenacity to yarn tenacity, its usefulness as a predictive equation for yarn tenacity is limited.

Elongation

Like fiber elongation, yarn elongation (%) measures the distance a yarn will stretch before breaking. Üreyan and Kadoğlu (2006) found that yarn elongation of ring-spun yarns increased with increasing fiber length and strength but decreased with increasing micronaire.

Tenacity

Yarn tenacity is a measure of the pressure required to break a yarn and is directly related to yarn strength. Yarn tenacity increases with increasing fiber strength (Graham and Taylor, 1978; Üreyan and Kadoğlu, 2006). Ramey et al. (1977) found that fiber tenacity measured at 3.2 mm gage length explained more than 70% of the variation in observed yarn tenacity. Longer, more uniform fibers also produce more tenacious yarns (Ramey et al., 1977; Müller, 1991; Üreyan and Kadoğlu, 2006). Graham and Taylor (1978) reported that yarn end-breaking strength is related to the slipping resistance of fibers, which will increase with length due to greater fiber-to-fiber bonds. Steadman et al. (1989) found that, at fine counts, rotor-spun yarn had fewer end breaks when combing, which primarily removes short fibers, was done.

Testing 42 cottons, Ramey et al. (1977) found no correlation between micronaire and yarn tenacity. Üreyan and Kadoğlu (2006) found that yarn tenacity was negatively correlated to micronaire. However, Üreyan and Kadoğlu (2006) correlated yarn properties with HVI fiber properties of fibers removed from the sliver after the finishing draw frame. Because an accurate measure of micronaire requires the fibers in the compressed sample to be randomly oriented, the relationship between yarn tenacity and the micronaire of a sample of parallelized fibers may not hold for samples taken directly from a bale of cotton.

Confirming the results of Hunter and Gee (1982), Frydrych (1992) concluded that fiber maturity and trash content do not influence yarn strength. Krifa et al. (2001) found that the effect of seed-coat fragments (SCF) on yarn strength varied with fiber quality: "…we hypothesize that SCF will only have a significant effect on yarn strength if the resistance at the point created by the SCF is even weaker than the weakest point already present" (Krifa et al., 2001).

Smith and Waters (1985) described the relationship between yarn twist and strength (fig. 15).

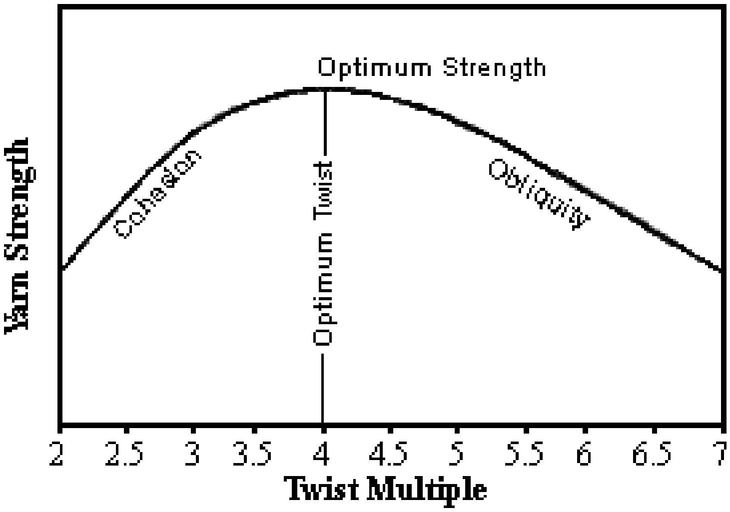


Figure 15. Example yarn twist curve (Smith and Waters, 1985).

Twist in yarns adds strength by tightening the yarn structure, thus decreasing fiber slippage. However, if excessive twist is added to the yarn, the obliquity of the fibers from the yarn axis decreases yarn strength (Smith and Waters, 1985). The twist multiplier is a constant which can be multiplied by the yarn number (cotton system) to determine the number of turns per inch of yarn.

Graham and Taylor (1978) tested the effects of roving evenness, spindle speed, twist, and front drafting roll load pressure on yarn strength of ring-spun yarns. They found that, of these parameters, yarn strength was most substantially affected by front-drafting roll pressure. The authors speculated that this was because the front-drafting roll pressure influences fiber cohesion in the yarn.

Evenness

Several parameters are used to indicate yarn evenness. Yarn coefficient of variation (CV) is a measure of the variability in the thickness of 100 m of yarn (eq. 5).

$$CV = \frac{\sigma}{\mu} * 100 \tag{5}$$

where: CV = coefficient of variation (%),

σ = standard deviation of yarn thickness about the mean, and

μ = mean yarn thickness.

Evenness can also be indicated by the number of thick and thin places (points in the yarn that are over 50% thicker than or less than 50% of the average thickness, respectively) per km of yarn.

For yarns coarser than 22 tex, rotor-spun yarns are generally more even (Steadman et al., 1989). Furthermore, Delhom et al. (2007) stated that fiber quality has a greater effect on the yarn quality (and especially the uniformity) of ring-spun yarns compared to rotor-spun yarns.

Üreyan and Kadoğlu (2006) found that yarn unevenness was positively correlated to fiber elongation but negatively correlated to fiber strength, reflectance and yellowness (which may indicate fiber maturity), length uniformity, and micronaire. Müller (1991) reported that yarn evenness was correlated to fiber length and length distribution. Steadman et al. (1989) found that fine count rotor-spun yarns had decreasing evenness with increasing twist.

Neps are perhaps the greatest cause of unevenness in yarns. Jones and Baldwin (1996) reported that most of the +200% imperfections in 20, 27, and 37 tex yarns they tested were due to seed-coat neps with correlations increasing for finer yarns. Frydrych and Matusiak (2002) developed theoretical estimations of the critical nep size in fibers, that is, the largest nep size permissible in AFIS fiber testing that will not show up in a yarn (as +200% imperfection) for open-end spinning (eq. 6) and ring spinning (eq. 7):

$$D_{crit} = 0.107T^{0.063} \tag{6}$$

$$D_{crit} = 0.138T^{0.663} \tag{7}$$

where: D_{crit} is the critical nep size (mm), and

T is the linear density of yarn (tex)

Experimental data supported the authors' theoretical conclusions.

Hairiness

Yarn hairiness is a measure of the number of fiber ends and loops protruding from the body of a yarn (Zhu and Ethridge, 1997). Hairy yarns tend to cling together in subsequent stages of processing making them difficult to manipulate. Dyed fabrics made from hairy yarns have an undesirable hazy appearance.

In general, ring-spun yarns are hairier than rotor-spun yarns of the same count, and coarse yarns are hairier than fine yarns (Barella and Manich, 1988). Barella and Manich (1988) found that ring-spun yarns of the same count were 2.5 times more hairy than rotor-spun yarns of the same count. They also found that fiber length, length uniformity, and micronaire explained only 33% of the hairiness of 15 tex ring-spun yarns and 18% of 30 tex ring-spun yarns. For rotor-spun yarns, fiber parameters explained 38-40% of hairiness for both 30 and 50 tex yarns.

Zhu and Ethridge (1997) reported that fiber length is the dominant fiber trait affecting yarn hairiness, confirming the results of Barella and Manich (1988). The authors found that increasing fiber length, strength, and elongation reduced hairiness for both ring and rotor-spun yarns. Correspondingly, yarns made from cottons with higher short fiber content (SFC) were hairier. The observed effect of these fiber properties on hairiness was greater for ring-spun yarns than for rotor-spun yarns. Viswanathan et al.

(1989) reported similar results for length and strength effects but reported that increased SFC led to less hairy yarns. However, the author noted that this observation was contradictory to other findings and may be the result of biased measurement techniques. Üreyan and Kadoğlu (2006) and Müller (1991) reported negative correlations between fiber length and yarn hairiness. Viswanathan et al. (1989) also found that fiber fineness had the greatest effect on yarn hairiness, followed by fiber length, whereas Zhu and Ethridge (1997) found no correlation between fiber fineness and yarn hairiness.

The results from Zhu and Ethridge (1997) contradicted the results of Viswanathan et al. (1989) with regards to the effect of fiber maturity on yarn hairiness as well. Zhu and Ethridge (1997) reported that increasing fiber maturity increased hairiness for both ring and rotor-spun yarns, while Viswanathan et al. (1989) and Pillay (1964) reported no significant correlation between fiber maturity and yarn hairiness. However, Viswanathan et al. (1989), Zhu and Ethridge (1997), and Üreyan and Kadoğlu (2006) found significant correlations between micronaire and yarn hairiness. Zhu and Ethridge (1997) reported that yarn hairiness was positively correlated to micronaire and fiber diameter for rotor-spun yarn but negatively correlated for ring-spun yarn. Üreyan and Kadoğlu (2006) found that hairiness of ring-spun yarns was positively correlated micronaire.

Noils

Noils are the waste from the combing process, which primarily removes short fibers from laps of cotton before finisher drawing and roving. Elevated noils represent waste in the processing stream, making the inputs to the finished yarn more expensive.

Previous Research

Baker and Brashears (2000) evaluated the effect of field cleaners on open-end spun yarn quality from three varieties of cotton. The field-cleaned cotton produced open-end spun yarn with a slightly higher evenness coefficient of variation (CV) and more thin places. All other measured yarn factors were unaffected by the use of a field cleaner.

McAlister and Rogers (2005) investigated the effect of harvesting method on fiber and yarn quality from Ultra-Narrow-Row cotton grown in South Carolina. The authors reported fewer thick places in yarns from picked cottons versus stripped cottons, while no significant differences were detected in other yarn quality indices. However, the samples analyzed in this study were not harvested until after Christmas due to extremely wet weather during the harvest season. Due to varietal differences, the use of Ultra-Narrow-Row cotton, and the extreme weathering of the cotton before harvest, the applicability of the results of this study is questionable.

The objective of this research was to examine the effects of harvest method between picker and stripper harvesters on yarn quality from irrigated cotton harvested on the High Plains of Texas with modern harvest equipment. This study represents the first commercial-scale harvester comparison project conducted in the High Plains region and the first study to analyze the effects of harvest method on ring-spun yarn quality from a traditional production system.

METHODS

Irrigated cotton was harvested from commercial farms on the High Plains of Texas and ginned at the USDA-ARS Cotton Production and Processing Research Unit in 2006 and 2007 as described in Chapter V. A minimum of 23 kg (50 lbs) of lint from each sample was processed into yarn at the International Textile Center. Figure 16 shows the process flow from bale to yarn for the samples collected. Approximately half of each sample was carded only while the other half of each sample was carded and combed.

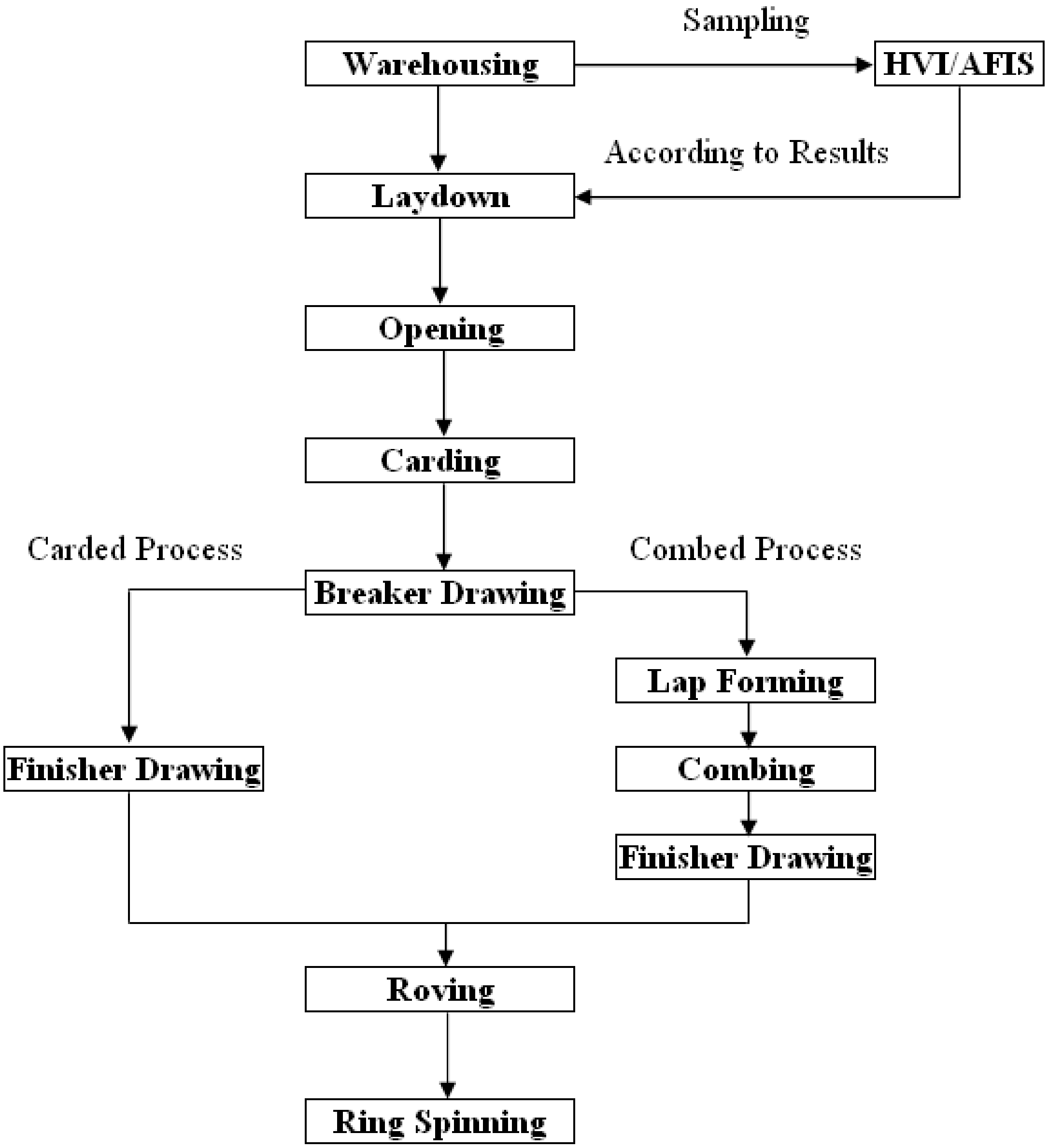


Figure 16. Spinning process flow chart for ring spinning.

Warehousing and Laydown

During warehousing, samples were conditioned and subsamples taken for HVI and AFIS analysis to determine the processing order. Based on the results of HVI micronaire tests, the laydown order was established based on sequential micronaire values so that the card could be calibrated to consistently achieve the desired air to fiber mass ratio in the chute feed.

Opening

Samples were divided and placed into four bins to start the opening process. Within each bin, flat and inclined conveyors moved cotton to a comb that reduced the tuft size before dropping the cotton onto a conveyor belt where it was mixed with cotton from each of the other three bins. The cotton was then pneumatically conveyed to a mono-cylinder, which is a half-beating point cleaner (i.e. a cleaning machine that does not restrain one end of the fiber) where the cotton is gently opened. The lint was then processed through an ERM, which is a full-beating point cleaner (i.e. a cleaning machine that restrains one end of the fiber) that uses triangular saw-tooth wire to pull cotton past a series of grid bars. Finally, the cotton was fed into an Automatic Material Handler (AMH), which is a feed control system that uses conveyors and a comb similar to the initial bins to feed cotton into the air stream leading to the carding machine.

Carding

From the AMH, cotton was pneumatically conveyed to the card (Model DK-903; Trützschler; Mönchengladbach, Germany) after passing an in-line metal detector to eliminate foreign matter than may damage the card. At the chute feed, cotton is drawn into the card evenly and drafted by feed rollers. Three licker-inn rollers opened and cleaned the cotton with pins (1st cylinder), coarse saw wire (2nd cylinder), and fine saw wire (3rd cylinder). Cotton was then drawn into a thin web on the card cylinder, which is a 130 cm (51 in) diameter cylinder that rotated at 460 rpm. The card cylinder drew the cotton past a series of three stationary flats with increasingly densely packed wire to thin and parallelize the web and then past rotating flats that further conditioned the web. Once the web was removed from the carding cylinder, it passed through two rollers that crush any remaining foreign matter and then through a trumpet, where the web was formed into a sliver, which is placed in a can. For this project, the sliver had a linear density of 4600 tex (65 gr/yd).

Breaker Drawing

Breaker drawing was conducted on an HSR 1000 draw frame (Trützschler; Mönchengladbach, Germany), bypassing the auto-leveler. Drawing was achieved by seven rollers (fig. 17). The bottom rollers were powered, and the top rollers rotated due to the friction of the sliver. During breaker drawing, "trailing hooks" are removed from the fibers.

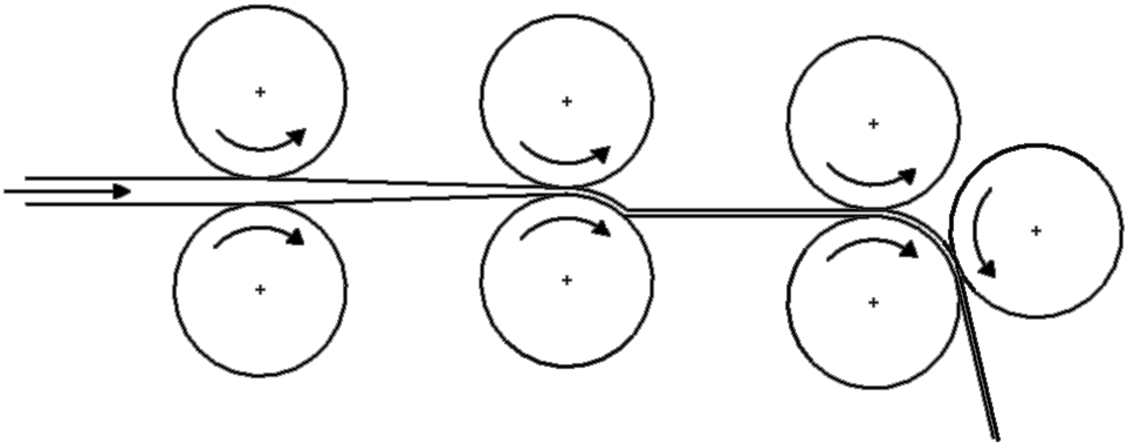


Figure 17. Draw frame rollers.

Each set of successive rollers (from left to right) rotate faster than the previous set, thus drafting the sliver. The distance between each set of rollers is set based on the fiber length. Therefore, before drawing, the cans from the web were organized sequentially by length. Each sliver from the card was divided into six slivers which were placed in the creel, from which they were fed into the draw frame. The six slivers were blended into one (on the left side of fig. 17) and drafted to form one sliver (exiting the right side of fig. 17). The draft is the ratio of the sliver linear density entering to the linear density exiting. For this project, the draft was 6.76, resulting in final linear density of 3900 tex (55 gr/yd). The sliver exiting the draw frame was split between two cans: 2740 m (3000 yards) of sliver were placed in a can for combing while the rest of the sliver was placed in a second can to form carded yarn. One can was taken directly to the finisher draw frame ("Carded Process" from fig. 16) and the other was formed into laps for combing.

Lap Forming and Combing

The sliver for carded-and-combed yarn tests was divided into 28 slivers that were blended and rolled into eleven laps. The first two laps and the final lap were discarded to avoid "piece ups." Each of the eight remaining laps was then combed and all laps were combined into a sliver with a final linear density of 3900 tex (55 gr/yd).

Finish Drawing

Both carded and carded-and-combed samples were divided into six can for finish drawing, which was again conducted on a HSR 1000 draw frame (Trützschler; Mönchengladbach, Germany). The finish draw frame operates in a similar manner to the breaker draw frame, but the fibers go through the rollers in the opposite direction as the breaker draw frame, thus removing "leading hooks" from the fibers. The final linear density of the sliver after finish drawing was 4250 tex (60 gr/yd).

Roving and Spinning

The final slivers for both combed samples and carded-and-combed samples were divided into ten cans which were placed on the roving frame, where they were combined, drawn, and placed on bobbins. A slight twist (0.51-0.63 turn/cm [1.29-1.59 turns/in]) was added to the sliver, which had a final linear density of 490 tex (hank roving of 1.2), to prevent breaking of the roving during spinning. The bobbins of roving were then spun on a Seussen Fiomax ring spinning frame. Bobbins were spun into 14.5 tex (40Ne) yarn with a twist multiple of 4.2 (weaving twist) using a traveler speed of 32 m/s. Ten bobbins of yarn were made from each sample.

Yarn Testing

Yarn count and skein break tests were conducted with a Scott Tester (ten bobbins tested per sample); yarn force to break, elongation, tenacity, and work to break were tested with a Uster Tensorapid 3 (ten bobbins tested per sample and ten breaks per bobbin); and yarn evenness was tested with an Uster Tester 3 (ten bobbins tested per sample and 400 m per bobbin).

All treatment means were compared with the General Linear Model function in SPSS (SPSS 14.0; SPSS, Inc.; Chicago, IL). A MANOVA test was conducted to determine overall differences between harvest treatments before conducting pair-wise comparisons. The null hypothesis tested in all cases was that means in each harvest treatment were equal. Means were compared with the Least Significant Difference (LSD) pair-wise multiple comparison test. A 0.05 level of significance was used in all tests.

In order to determine whether the fiber properties that are improved by picker harvesting versus stripper harvesting are significant contributors to yarn quality parameters, the relative contributions of fiber properties to yarn properties were analyzed using a stepwise linear regression (SPSS 14.0; SPSS, Inc.; Chicago, IL). The stepwise linear regression in SPSS is a forward regression in which, after a new variable is added to the regression model, the new p-value of all variables already in the model are checked to determine if they should remain in the model based on the user-specified significance level for inclusion. For the regression analysis, data from 2006 and 2007 were combined, yielding 28 data points for each regression. Carded yarns were analyzed separately from carded-and-combed yarns. No significant autocorrelation was detected for any of the regression analyses presented.

RESULTS AND DISCUSSION

Because samples collected in 2007 were substantially more mature than samples collected in 2006, the results from each year are presented separately.

2006

Selected results of carded-and-combed yarn testing are shown in tables 23 and 24, respectively. Treatment differences were detected in carded yarn tests (p=0.024 using Wilk's Lambda) but not carded-and-combed yarn tests (p=0.205 using Wilk's Lambda) with MANOVA (n = 4 for each treatment). Therefore, pair-wise comparison tests of carded yarn tests may be analyzed as presented while combed yarn tests should be analyzed with more caution as an insignificant MANOVA result indicates an increased likelihood of a Type I error in which the null hypothesis is rejected even though it is true.

Table 23. Selected results of 2006 carded yarn analysis.[a]

	Picked		Stripped with FC		Stripped without FC	
	Value	Quality[b] (%)	Value	Quality[b] (%)	Value	Quality[b] (%)
CSP (N.tex)	2872.9x	N/A	2852.8x	N/A	2809.1x	N/A
Elongation (%)	7.80x	<5	7.91x	<5	7.87x	<5
Tenacity (cN/tex)	11.89x	>95	11.86x	>95	11.94x	>95
Work to Break (cN.cm)	376.5 x	49	380.4 x	47	382.0x	46
CV (%)	22.67x	>95	23.43y	>95	23.32x,y	>95
Thin Places (cnt/km)	597x	>95	742x	>95	736x	>95
Thick Places (cnt/km)	1641x	>95	1837x	>95	1808x	>95
Neps +200% (cnt/km)	1542x	>95	1787x	>95	1785x	>95
Hairiness	4.75x	14	5.08y	27	5.16y	30

[a] No significant differences were detected ($\alpha = 0.05$) between means in the same row followed by the same letter.

[b] Quality percentile is based on global yarn quality statistics for ring-spun carded yarn bobbins for weaving (USTER Technologies, 2007).

Table 24. Selected results of 2006 carded-and-combed yarn analysis.[a]

	Picked		Stripped with FC		Stripped without FC	
	Value	**Quality**[b] **(%)**	**Value**	**Quality**[b] **(%)**	**Value**	**Quality**[b] **(%)**
Noils (%)	17.05x	N/A	17.65x	N/A	18.52y	N/A
CSP (N.tex)	3378.4x	N/A	3309.6x	N/A	3274.8x	N/A
Elongation (%)	7.98x	<5	8.00x	<5	8.01x	<5
Tenacity (cN/tex)	13.42x	>95	13.40x	>95	13.26x	>95
Work to Break (cN.cm)	436.3x	14	433.5x	17	428.8x	20
CV (%)	16.81x	91	17.24y	>95	17.37y	>95
Thin Places (cnt/km)	47x	>95	58y	>95	55x,y	>95
Thick Places (cnt/km)	290x	89	348y	92	360y	92
Neps +200% (cnt/km)	1030x	>95	1260y	>95	1320y	>95
Hairiness	4.22x	39	4.41y	50	4.49y	55

[a] No significant differences were detected ($\alpha = 0.05$) between means in the same row followed by the same letter.

[b] Quality percentile is based on global yarn quality statistics for ring-spun combed yarn bobbins for weaving (USTER Technologies, 2007).

Little difference was detected in carded yarn quality based on harvest treatment with the exception of hairiness. However, greater differences were detected in carded-and-combed yarn quality indices. In addition to the reduced percentage of noils seen in picked and field-cleaned cotton, picked cotton had a smaller CV, fewer thick and thin places, fewer neps, and was less hairy than both stripped treatments. It should be noted, however, that combing is not typically performed on fibers with a staple shorter than 36, which was the case for all three harvest treatments. Unlike Baker and Brashears (2000), no differences were seen in yarn evenness between field-cleaned and non-field-cleaned cotton, but Baker and Brashears (2000) analyzed open-end spun yarn rather than ring-spun yarn.

Compared to global averages, the yarn quality indices reported above for all harvest treatments indicate relatively poor yarn quality with a few exceptions: elongation for both carded and carded-and-combed yarns was excellent; work-to-break was average for carded yarns but good for carded-and-combed yarns; and hairiness, which was near average for carded-and-combed yarns but good for carded yarns.

2007

Selected results of carded-and-combed yarn testing are shown in tables 25 and 26, respectively. A MANOVA test using Wilk's Lambda (n = 24 for each treatment) revealed significant differences in carded yarn test results as a function of harvest location ($p < 0.0005$), variety ($p < 0.0005$), and harvest treatment ($p = 0.026$). Multivariate interactions were also significant between variety and location ($p < 0.0005$).

For carded-and-combed yarn tests, significant differences were detected as a function of harvest location ($p < 0.0005$) and variety ($p < 0.0005$) but not harvest treatment ($p = 0.150$). Therefore, pair-wise comparisons of carded yarn tests (table 25) may be analyzed as presented while carded-and-combed yarn tests (table 26) should be analyzed with more caution given the increased likelihood of a Type I error. For carded-and-combed tests, multivariate interactions were also significant between variety and location ($p = 0.001$).

Table 25. Selected results of 2007 carded yarn analysis.[a]

	Picked		**Stripped with FC**		**Significant Variables**[c]
	Value	**Quality**[b] **(%)**	**Value**	**Quality**[b] **(%)**	
CSP (N.tex)	3781.3x	N/A	3752.3x	N/A	V, L, V*L
Elongation (%)	6.79x	<5	6.74x	<5	V, L, V*L
Tenacity (cN/tex)	14.48x	>95	14.20y	>95	V, T, V*L
Work to Break (cN.cm)	376.4x	49	369.3x	49	V, L, V*L
CV (%)	19.77x	83	19.88x	85	V, L, V*L
Thin Places (cnt/km)	189x	95	198x	>95	V, L, V*L
Thick Places (cnt/km)	931x	92	964x	94	V, L, V*L
Neps +200% (cnt/km)	741x	71	797y	77	V, L, T, V*L
Hairiness	4.66x	10	4.74y	14	V, L, T, V*L

[a] No significant differences were detected ($\alpha = 0.05$) between means in the same row followed by the same letter.

[b] Quality percentile is based on global yarn quality statistics for ring-spun carded yarn bobbins for weaving (USTER Technologies, 2007).

[c] V = variety; L = location; T = harvest treatment; V*L = variety-location interaction.

Table 26. Selected results of 2007 carded-and-combed yarn analysis.[a]

	Picked		Stripped with FC		Significant Variables[c]
	Value	Quality[b] (%)	Value	Quality[b] (%)	
Noils (%)	16.50x	N/A	16.93x	N/A	V, L, V*L
CSP (N/tex)	4225.7x	N/A	4184.0x	N/A	V, V*L
Elongation (%)	7.10x	<5	7.04x	<5	V, L, V*L
Tenacity (cN/tex)	15.86x	90	15.83x	91	V, V*L
Work to Break (cN.cm)	427.2x	20	421.4x	22	V, V*L
CV (%)	14.98x	70	15.07x	72	V, L, V*L
Thin Places (cnt/km)	16x	84	17x	85	V, L
Thick Places (cnt/km)	108x	76	117y	77	V, L, T, V*L
Neps +200% (cnt/km)	59x	31	69y	39	V, L, T, V*L
Hairiness	4.22x	39	4.26x	41	V, L, V*L

[a] No significant differences were detected ($\alpha = 0.05$) between means in the same row followed by the same letter.

[b] Quality percentile is based on global yarn quality statistics for ring-spun combed yarn bobbins for weaving (USTER Technologies, 2007).

[c] V = variety; L = location; T = harvest treatment; V*L = variety-location interaction.

As with the fiber quality parameters (tables 19-21), varietal and location impacts were substantial. Therefore, paired-sample t-tests ($\alpha = 0.05$) were conducted comparing differences in yarn properties between picked and stripped samples from the same plot to reduce varietal and location impacts. Results of the paired-samples t-tests for carded yarns revealed significant improvements in CSP, tenacity, nep count, and yarn hairiness from picked samples versus stripped samples (table 27). For carded-and-combed samples, picked cottons had fewer noils and resulted in improvements in yarn evenness and nep counts relative to stripped cottons (table 28). The percentage fibers combed out of the laps as noils was significantly correlated to SFC ($p < 0.0005$).

Table 27. Selected paired-sample t-test results of 2007 carded yarn analysis.

	Mean Difference[a]	p-value
CSP (N.tex)	27.3	0.030
Tenacity (cN/tex)	0.28	0.015
Neps + 200% (cnt/km)	-55	0.006
Hairiness	-0.08	0.003

[a] Mean difference = (Avg. of picked sample) – (Avg. of stripped samples).

Table 28. Selected paired-sample t-test results of 2007 carded-and-combed yarn analysis.

	Mean Difference[a]	p-value
Noils (%)	-0.425	0.002
CV (%)	-0.09	0.039
Thick Places (cnt/km)	-9.3	0.011
Neps + 200% (cnt/km)	-10.1	<0.0005

[a] Mean difference = (Avg. of picked sample) – (Avg. of stripped samples).

Compared to 2006, carded yarn tests in 2007 for both picked and stripped (field-cleaned) samples showed increases in strength (as demonstrated by increases in CSP and tenacity; $p < 0.0005$ for all tests) but decreases in elongation ($p = 0.031$ for picked; $p = 0.025$ for stripped), which led to no significant differences in work to break ($p = 0.997$ for picked; $p = 0.677$ for stripped). Yarns in 2007 were also more even, as demonstrated by improvements in CV, thin places, thick places, and neps (+200%; $p < 0.0005$ for all tests). Hairiness improved for stripped samples between 2006 and 2007 ($p = 0.006$) but not for picked samples.

Combing was more appropriate for samples in 2007, when the average staple was 37, than 2006, when the average staple was 35. Like the carded yarn tests, both picked and stripped (field-cleaned) samples showed increases in strength (as demonstrated by increases in CSP and tenacity; $p < 0.0005$ for all tests). While differences in elongation were not significant at the 95% confidence interval ($p = 0.067$ for picked; $p = 0.053$ for stripped), reductions in elongation were enough to offset gains in yarn strength such that no significant differences were detected in work to break ($p = 0.711$ for picked; $p = 0.658$ for stripped). Carded-and-combed yarns in 2007 were also more even, as demonstrated by improvements in CV, thin places, thick places, and neps (+200%; $p < 0.0005$ for all tests). No differences were detected between years in hairiness or noils for either harvest treatment.

Like 2006, compared to global averages, the yarn quality indices reported above for all harvest treatments indicate relatively poor yarn quality with a few exceptions: elongation for both carded and carded-and-combed yarns was excellent; work-to-break was average for carded yarns but good for carded-and-combed yarns; and hairiness, which was near average for carded-and-combed yarns but good for carded yarns.

Data Correlations

Prediction equations from the multiple linear regression analysis are of the form:

$$Y = A + \sum_{i=1}^{n} C_i x_i \tag{8}$$

where: Y = value of predicted yarn parameter,
A = regression constant,
C_i = coefficient of the i^{th} prediction variable,
x_i = value of the i^{th} prediction variable, and
n = number of significant prediction variables in the regression.

Count Strength Product

Count strength product should increase with increases in fiber strength and intermolecular forces between fibers. At a given yarn count, the number of fibers in the yarn cross section will increase as fiber fineness increases, and fiber strength will increase as fiber maturity increases. However, the presence of foreign matter may reduce forces between fibers. Therefore, candidate variables for the CSP regression analysis included micronaire, fiber length, length uniformity, strength, elongation, color (which may indicate weathered fibers), short fiber content, maturity, fineness, and foreign matter content.

The stepwise regression analysis of the effect of fiber properties on CSP is summarized in table 29. Upper quartile length (UQL) from AFIS measurements alone accounted for almost 80% of the variation in CSP of carded-and combed yarns and over 85% in carded yarns.

Table 29. Regression analysis for CSP from fiber properties.

Prediction Variable	Coefficient	R^2	Increase in R^2	p-value
Carded Yarn				
Constant	-1773.9	--	--	0.003
UQL[a] (cm)	1454.5	0.856	0.856	<0.0005
SFC_w[b] (%)	-31.9	0.894	0.038	<0.0005
Carded-and-Combed Yarn				
Constant	-7418.9	--	--	<0.0005
UQL[a] (cm)	949.8	0.790	0.790	<0.0005
Maturity Ratio	5469.1	0.857	0.067	<0.0005
Micronaire	-153.9	0.867	0.011	0.036
VFM[c]	121.8	0.886	0.018	<0.0005
Reflectance	36.3	0.905	0.019	0.002

[a] UQL = upper quartile length
[b] SFC_w = short fiber content by weight
[c] VFM = visible foreign matter

The results of the regression analyses support the findings of El Mogahzy (1988) that CSP increases with increasing fiber length over the range of fiber lengths investigated (2.79 cm < UQL < 3.25 cm). However, unlike El Moghazy (1988) no correlation was seen between CSP and fiber strength or length uniformity.

Of the significant predictive variables for CSP from carded yarn, short fiber content (SFC) was significantly impacted by harvester treatment in 2007 (table 21). Short fiber content only accounted for 4% of the variation in CSP of carded yarns. Upper quartile length, which accounted for over 85% of the variability in CSP in carded yarn, is primarily a function of variety rather than harvest treatment. Even so, in 2007 there was a slight difference in CSP in carded yarns as a function of treatments in 2007 (table 27).

For carded-and-combed yarns, the variables influencing CSP that are affected by harvest treatment (maturity ratio in 2007 and micronaire) account for only 8% of the variation in CSP. Therefore, it is not surprising that no differences were detected in CSP between harvest treatments for carded-and-combed yarns.

Elongation

Yarn elongation should increase with increases in fiber elongation and intermolecular forces between fibers. Increases in fiber strength should also permit greater yarn elongation before breaking. Therefore, candidate variables for the yarn elongation regression analysis included micronaire, fiber length, length uniformity, strength, elongation, color (which may indicate weathered fibers), short fiber content, maturity, fineness, and foreign matter content.

The stepwise regression analysis of the effect of fiber properties on yarn elongation is summarized in table 30. Fiber fineness and micronaire account for most of the variation in yarn elongation of both carded yarns and carded-and-combed yarns.

Table 30. Regression analysis for yarn elongation from fiber properties

Prediction Variable	Coefficient	R^2	Increase in R^2	p-value
		Carded Yarn		
Constant	-15.0	--	--	<0.0005
H_s[a] (mtex)	0.098	0.671	0.671	<0.0005
Micronaire	-1.06	0.833	0.162	<0.0005
Elongation (%)	0.44	0.896	0.062	<0.0005
HVI Length (cm)	2.86	0.915	0.019	<0.0005
Strength (g/tex)	-0.12	0.930	0.015	<0.0005
Yellowness	-0.19	0.936	0.006	0.027
		Carded-and-Combed Yarn		
Constant	-16.3			<0.0005
H_s[a] (mtex)	0.10	0.707	0.707	<0.0005
Micronaire	-1.14	0.832	0.125	<0.0005
Elongation (%)	0.42	0.918	0.086	<0.0005
UQL[b] (cm)	2.03	0.936	0.018	<0.0005
VFM[c]	-0.14	0.944	0.009	0.005

[a] H_s = standard fineness
[b] UQL = upper quartile length
[c] VFM = visible foreign matter

The results of the regression analyses support the findings of Üreyan and Kadoğlu (2006) that yarn elongation increases with increasing fiber length and decreasing micronaire. However, Üreyan and Kadoğlu (2006) found no significant relationship between fiber fineness and yarn elongation.

Of the significant predictive variables for yarn elongation having a substantial impact, only micronaire was significantly impacted by harvester treatment (tables 17-21). Therefore, it is not surprising that no differences were seen in yarn elongation between harvest treatments.

Tenacity

Yarn tenacity increases with increasing yarn strength and elongation. Therefore, candidate variables for the yarn tenacity regression analysis include those for both yarn CSP and elongation.

The stepwise regression analysis of the effect of fiber properties on yarn tenacity is summarized in table 31. The initial regression model for carded-and-combed yarns indicated that yarn tenacity was negatively correlated to standard fineness, but the model was revised because, all else being equal, finer fibers should result in stronger (and therefore more tenacious) yarns. Upper quartile length (UQL) from AFIS measurements alone accounted for almost 80% of the variation in yarn tenacity of carded yarns and 75% of the variation in carded-and-combed yarns.

Table 31. Regression analysis for yarn tenacity from fiber properties.

Prediction Variable	**Coefficient**	**R^2**	**Increase in R^2**	**p-value**
Carded Yarn				
Constant	-15.45	--	--	<0.0005
UQL[a] (cm)	17.87	0.792	0.792	<0.0005
Maturity Ratio	9.73	0.821	0.028	0.004
Carded-and-Combed Yarn				
UQL[a] (cm)	3.60	0.744	0.744	0.015
Elongation (%)	-0.52	0.776	0.032	<0.0005
SFC_w[b] (%)	-0.132	0.813	0.037	0.025
Strength (g/tex)	0.15	0.828	0.016	0.039
VFM[c]	0.25	0.841	0.013	0.042

[a] UQL = upper quartile length
[b] SFC_w = short fiber content by weight
[c] Visible foreign matter

Several previous studies (Ramey et al., 1977; Graham and Taylor, 1978; Üreyan and Kadoğlu, 2006) have reported significant correlations between fiber strength and yarn tenacity. Ramey et al. (1977) reported that variations in fiber tenacity accounted for 70% of variations in yarn tenacity. However, in this study no correlation was seen ers (Graham and Taylor, 1978; Ramey et al., 1977; Müller, 1991; Üreyan and Kadoğlu, 2006) that longer fibers produce more tenacious yarns due to increased fiber cohesion. between yarn strength and fiber strength for carded yarns, and in carded-and-combed yarns, variations in fiber strength explained only a small portion of the variation in yarn tenacity. However, the finding that UQL accounted for most of the variation in yarn tenacity supports the findings of several other research

Based on the regression tests performed, significant variations in yarn tenacity as a result of harvest treatment would not be expected as UQL is not significantly affected by harvest treatment. Differences in tenacity between carded yarns from picked and stripped samples in 2007 were likely the result of interactions between fiber properties or the result of a predictive variable that did not appear significant in this analysis due to the limited sample size. No differences were detected in yarn tenacity between harvest treatments in 2006.

Evenness

The evenness of yarns should improve as the fibers constituting a given yarn and the spinning conditions become more consistent. Therefore, it is expected that increased yarn unevenness would result from decreasing fiber uniformity and the presence of short fibers, neps, foreign matter, and weathered fibers. Immature fibers that cannot stand the forces of spinning may also lead to yarn unevenness. Candidate variables for evenness regression analyses included micronaire, fiber length, length uniformity, strength, elongation, color, short fiber content, maturity, fineness, and foreign matter content.

The stepwise regression analysis of the effect of fiber properties on yarn evenness is summarized in table 32. Substantially different results were found between carded yarn tests and carded-and-combed yarn tests. Mean length by number measurements from AFIS alone accounted for almost 90% of the variation in yarn evenness of carded yarns, while fiber length did not appear as a significant prediction variable for carded-and-combed yarns. Results of regression analyses for thick places, thin places, and nep counts (+200%) are summarized in tables 33-35. Short fiber content accounted for around 90% of the variation in thin places and yarn neps for carded yarns. Short fiber content also accounted for over 80% of the variation in thin and thick places in carded-and-combed yarns.

Table 32. Regression analysis for yarn mass CV from fiber properties.

Prediction Variable	Coefficient	R^2	Increase in R^2	p-value
Carded Yarn				
Constant	46.03	--	--	<0.0005
AFIS Length (cm)	-4.89	0.882	0.882	<0.0005
Uniformity (%)	-0.36	0.902	0.020	<0.0005
H_s[a] (mtex)	0.065	0.916	0.014	<0.0005
Leaf	0.404	0.931	0.015	<0.0005
VFM[b]	-0.45	0.943	0.012	<0.0005
Carded-and-Combed Yarn				
SFC_w[c] (%)	0.21	0.848	0.848	<0.0005
H_s[a] (mtex)	0.55	0.885	0.037	<0.0005
VFM[b]	-0.33	0.894	0.009	<0.0005
Leaf	0.30	0.919	0.026	<0.0005

[a] H_s = standard fineness
[b] VFM = visible foreign matter
[c] SFC_w = short fiber content by weight

The results of the regression analysis of carded yarn mass CV support the findings of Müller (1991) that yarn evenness is correlated to fiber length and length uniformity. Üreyan and Kadoğlu (2006) also reported that yarn evenness was negatively correlated to fiber length uniformity.

The reasons behind such diverse results for carded yarns versus carded-and-combed yarns are not clear. Based on the regression analysis, yarn evenness was primarily predicted by fiber quality parameters that are unaffected by harvest treatment. However, differences in yarn CV were detected for carded-and-combed yarns in both 2006 and 2007.

Table 33. Regression analysis for thin places from fiber properties.

Prediction Variable	Coefficient	R^2	Increase in R^2	p-value
Carded Yarn				
Constant	-2495.5	--	--	<0.0005
SFC_w[a] (%)	114.2	0.893	0.893	<0.0005
Length CV (%)	-62.8	0.905	0.012	<0.0005
Maturity Ratio	4495.0	0.913	0.008	<0.0005
IFC[b] (%)	88.1	0.936	0.023	0.001
SCN Size[c] (µm)	0.19	0.942	0.006	0.036
Nep Count (cnt/g)	0.40	0.947	0.004	0.046
Carded-and-Combed Yarn				
Constant	-142.1	--	--	<0.0005
SFC_w[a] (%)	3.72	0.819	0.819	<0.0005
SCN Size[c] (µm)	0.033	0.856	0.037	0.001
H_s[d] (mtex)	0.48	0.880	0.024	0.002

[a] SFC_w = short fiber content by weight

[b] IFC = immature fiber content

[c] SCN Size = seed-coat nep size

[d] H_s = standard fineness

Table 34. Regression analysis for thick places from fiber properties.

Prediction Variable	Coefficient	R^2	Increase in R^2	p-value
Carded Yarn				
Constant	6884.4	--	--	<0.0005
AFIS Length (cm)	-1276.7	0.883	0.883	<0.0005
Uniformity (%)	-85.2	0.904	0.022	<0.0005
Trash Size (µm)	2.95	0.923	0.019	0.001
H_s[a] (mtex)	16.2	0.931	0.008	0.002
Elongation (%)	-51.1	0.936	0.005	0.040
Carded-and-Combed Yarn				
Constant	-292.6	--	--	<0.0005
SFC_w[b] (%)	22.7	0.872	0.872	<0.0005
SCN Size[c] (µm)	0.18	0.901	0.029	<0.0005
Leaf Grade	13.3	0.910	0.009	0.023

[a] H_s = standard fineness

[b] SFC_w = short fiber content by weight

[c] SCN Size = seed-coat nep size

Table 35. Regression analysis for yarn neps (+200%) from fiber properties.

Prediction Variable	Coefficient	R^2	Increase in R^2	p-value
Carded Yarn				
SFC_w[a] (%)	135.2	0.908	0.908	<0.0005
Length (cm)	-705.2	0.921	0.013	0.007
Elongation (%)	-63.2	0.932	0.011	0.008
IFC[b] (%)	228.3	0.940	0.007	<0.0005
Length CV (%)	-88.8	0.948	0.009	<0.0005
Maturity Ratio	5906.5	0.956	0.007	0.001
H_s[c] (mtex)	12.6	0.959	0.003	0.041
Carded-and-Combed Yarn				
Constant	540.1	--	--	0.015
Nep Count (cnt/g)	0.29	0.869	0.869	<0.0005
SCN Size[d] (µm)	0.16	0.906	0.038	<0.0005
Uniformity (%)	-8.54	0.922	0.016	0.001

[a] SFC_w = short fiber content by weight
[b] IFC = immature fiber content
[c] H_s = standard fineness
[d] SCN Size = seed-coat nep size

Hairiness

As described above, previous researchers have found contradictory results regarding the influence of fiber properties on yarn hairiness. Furthermore, relative to other yarn properties, yarn hairiness has been poorly predicted by regression analyses of fiber properties. All HVI and AFIS fiber properties were considered as candidate variables for the yarn hairiness regression analysis model.

The stepwise regression analysis of the effect of fiber properties on yarn hairiness is summarized in table 36. Less than 70% of the variation in yarn hairiness is explained by the regression model.

Table 36. Regression analysis for yarn hairiness from fiber properties.

Prediction Variable	Coefficient	R^2	Increase in R^2	p-value
Carded Yarn				
Constant	17.74	--	--	<0.0005
Uniformity (%)	-0.16	0.648	0.648	<0.0005
Trash[a] (cnt/g)	0.001	0.677	0.030	0.026
Carded-and-Combed Yarn				
SCN Size[b] (µm)	-0.001	0.479[c]	0.479	<0.0005
SFC_w[d] (%)	0.09	0.562	0.083	<0.0005
Maturity Ratio	4.92	0.627	0.065	<0.0005
Nep Size (µm)	0.003	0.653	0.027	0.044

[a] The number of particles larger than 500 µm per gram as counted by AFIS

[b] SCN Size = seed-coat nep size

[c] The model originally introduced length uniformity before SCN Size, but length uniformity was eliminated as a prediction variable in a later step. Therefore, SCN Size alone does not account for 47.9% of the variability in carded-and-combed yarn hairiness.

[d] SFC_w = short fiber content by weight

The results of this regression analysis are dissimilar to the results of many other researchers (Barella and Manich, 1988; Viswanathan et al., 1989; Müller, 1991; Zhu and Ethridge, 1997; Üreyan and Kadoğlu, 2006), who identified fiber length as a dominant trait affecting yarn hairiness. Length was not a significant predictor ($p = 0.828$ for carded yarns; $p = 0.541$ for carded-and-combed yarn) in the present regression models. However, as in the carded yarn model, Barella and Manich (1988) reported correlations between length uniformity and yarn hairiness. The results of the carded-and-combed yarn regression model agree with the results of Zhu and Ethridge (1997) in that SFC and fiber maturity were both positively correlated with yarn hairiness.

No previous studies were reviewed that related trash content to yarn hairiness. The reasons for the discrepancy in results between this investigation and previous studies are unclear at this time. It is notable that significant differences in yarn hairiness were detected in both 2006 and 2007 even through differences in fiber length uniformity by harvest treatment were detected in 2006 only.

CONCLUSIONS

Harvest treatments were compared on the basis of yarn quality indices for four varieties of cotton commonly grown on the High Plains of Texas over two years. Regression analyses were also conducted to determine relationships between fiber and yarn properties.

Few differences were detected in carded yarn quality between harvest treatments, while more pronounced differences favoring picked cotton were seen in carded-and-combed yarns. During both 2006 and 2007, the evenness of carded-and-combed yarns was improved by picking over stripping as measured by yarn CV, thick places, and neps (+200%), and the hairiness of carded yarns was reduced by picking. In 2007, when fibers were more mature, picking improved the CSP, tenacity, and nep counts of carded yarns. Noils, which were correlated to SFC, were also reduced by picking. In 2007, variety had a greater impact on yarn quality than harvest treatment.

Results of regression analyses were largely consistent with the findings of previous investigations with regards to CSP, yarn elongation, and carded yarn evenness. Contrary to previous studies, no significant relationships were detected between yarn tenacity and fiber strength or between fiber length and yarn hairiness.

CHAPTER VII
ECONOMIC ANALYSIS

INTRODUCTION

Cotton production in the High Plains has changed dramatically in the past ten years as new varieties with superior quality characteristics have been introduced to the region and irrigated production area has increased. As consumption of US cotton has shifted from domestic mills to an export market, demands for increased quality have forced producers to reevaluate their production and marketing goals, leading to changes in on-farm management practices that have resulted in dramatic increases in length and strength grades for cotton classed at the USDA-AMS Cotton Classing Offices in Lubbock and Lamesa, Texas. Furthermore, it is estimated that between 120,000 and 160,000 ha (300,000 and 400,000 ac) of drip irrigation has been installed on the High Plains in the past ten years for cotton production, and over 450,000 ha (1.1 million ac) are irrigated with center pivot systems equipped with high efficiency application packages. As a result, yield potentials in the region have dramatically increased, sometimes reaching 9.8 to 12.3 bales/ha (4 to 5 bales/ac). The increased emphasis on quality coupled with increased yields have renewed interest in picker harvester systems as a means of preserving fiber quality as cotton moves from the field to the mill. Although picker harvesters are more expensive to purchase and operate, improvements in the quality of cotton harvested and increases in the speed of harvest may make them an attractive option to producers of irrigated cotton on the High Plains.

Several economic analyses have attempted to evaluate various cotton harvest systems. Vories and Bonner (1995) compared gross returns per unit area from picked and stripped cotton and found that on average, the stripper system produced a greater return to the producer. However, this study was conducted on cotton yielding less than 4.9 bales/ha (2 bales/ac) and may not be reflective of returns in higher yielding cotton. Vories and Bonner (1995) also made no attempt to analyze differences in operational costs between systems but compared returns based on lint value only. Faircloth et al.

(2004) found similar results in northeast Louisiana, but their comparison suffered from similar deficiencies.

Nelson et al. (2001) compared alternative stripper and picker harvesting systems and included operational and maintenance costs for each system along with the cost of custom harvesting as an alternative to equipment ownership. The analysis by Nelson et al. (2001) includes many important considerations and may serve as a model for further comparisons, but Nelson et al. (2001) only compared different stripper systems with other stripper systems and picker systems with other picker systems. No comparison was made between picker- and stripper-based harvest systems. Spurlock et al. (2006) conducted a similarly robust economic analysis comparing different row configurations for picker harvesters, but again, no comparison was made between picker and stripper systems.

Yates et al. (2007) proposed results for an economic study comparing picker and stripper harvesters, but he extrapolated the fiber quality results from an older two-row model picker to a new six-row picker and from an older four-row stripper to a new eight-row picker. Yates et al. (2007) states that "performance rates" were used in the model, but no discussion is given regarding the information included in those "performance rates." Yates et al. (2007) described the economic model used as the Cotton Economics Research Institute Cotton Harvesting Cost Calculator, but gave no details of the model. Given the lack of information and the questionable extrapolation, the results of Yates et al. (2007) should not be considered as a viable economic model.

Willcutt et al. (2001) described the most comprehensive economic model for comparing harvest systems with the COTSIM cotton harvester simulation model developed by Chen et al. (1992). Willcutt et al. (2001) simulated various harvesters on various size farms with different row configurations (e.g. skip-row, solid rows, etc.), but all production systems were assumed to yield 980 kg of lint per ha (1.8 bales/ac). Willcutt et al. (2001) found that, even with a 2.3 cent per kg ($0.05/lb) reduction in price for lint, stripper systems yielded higher net returns than picker systems. However, Willcutt et al. (2001) assumed similar basket volumes for both machines, assumed that strippers could operate the same number of hours per day as pickers, and that the same number of modules would be produced from both systems. All of these assumptions are erroneous and may significantly affect harvest system economics. Willcutt et al. (2001) concluded, however, that if strippers were operated fewer hours per day than pickers and the number of harvest days available was limited, returns from stripper systems quickly fell to or below the level of returns from picker harvesters. Furthermore, Willcutt et al. (2001) did not account for slower stripper speeds that will result from higher yielding stands, which also favor picker-based systems.

While each of the aforementioned studies yields insight into the decision matrix needed to determine the best harvest system for irrigated cotton on the High Plains, none of these studies addresses the issue holistically.

Several well-known financial metrics are available to assess the economic impact of an investment, including payback period (PP), return on investment (ROI), return on assets (ROA), and net present value (NPV) (Flaig, 2005). While each of these metrics is important to consider, only NPV considers the time value of money (Blanchard and Fabrycky, 1990).

The objective of this research is to use an NPV model to compare economic returns for picker and stripper harvesters on the High Plains of Texas. Model inputs regarding harvester performance and cotton fiber quality from each system were determined from field measurements described in previous chapters. Six-row picker and stripper systems were compared.

METHODS

NPV for each system was calculated as (Bowlin et al., 1990):

$$NPV = \sum_{t=0}^{n} \frac{C_t}{(1+k)^t} \tag{9}$$

where: NPV = net present value ($),

n = duration of the investment,

C_t = net cash flow at time period t, and

k = discount rate.

For a given area harvested per machine, the yield required for the NPV of a picker system to equal the NPV of a stripper system with a field cleaner and a stripper system bypassing a field cleaner were calculated.

Base Scenario

In the base scenario, the investment cost was determined assuming that each machine was purchased with 100% liability and the purchase was amortized into equal payments over seven years, assuming the salvage value as the future value. The real interest rate (4.8%) was assumed as the discount rate (eq. 10; Bowlin et al., 1990) and was calculated using the average 2007 intermediate agricultural lending rate (9.28%; Federal Reserve Bank of Dallas, 2008) adjusted by the farm machinery inflation rate (4.3%; USDA-NASS, 2008a).

$$k = \frac{(1 + NR)}{(1 + IR)} - 1 \tag{10}$$

where: k = real discount rate,

NR = nominal rate (here, intermediate agricultural lending rate), and

IR = inflation rate (here, intermediate agricultural lending rate).

The cost of each machine was calculated assuming a purchase price of 90% of the MSRP (Spurlock et al., 2006) and a salvage value equal to 45% of the purchase price (Nelson et al., 2001). Taxes, housing, and insurance were calculated as 2% of the purchase price per year (ASAE Standards, 2006).

Harvester operation parameters and turnout were estimated based on field measurements from the 2006 and 2007 harvest seasons (table 37).

Table 37. Harvester parameter inputs measured during 2006 and 2007 harvest seasons.

	Picker	Stripper with Field Cleaner	Stripper without Field Cleaner
Speed (kph [mph])	6.1 (3.8)	5.5 (3.4)	5.5 (3.4)
Basket Capacity (bales)	4.8	2.1	1.8
Dump Time (s)	76	45	45
Lint Turnout (%)	35	30	27
Seed Turnout (%)	55	46	40

A row spacing of 76 cm (30 in.) was assumed. Harvester fuel use was estimated at 26.2 and 13.1 L/ha (2.8 and 1.4 gal/ac) for the picker and stripper, respectively, and a spot diesel price of \$0.86/L (\$3.25/gal) was assumed. A single application of harvest aid was assumed for picked cotton at \$25/ha (\$10/ac), whereas a second harvest aid application (at an additional cost of \$25/ha) was assumed for stripped cotton. Labor costs were a function of the time required to harvest a given area based on measured time-in-motion data, and a labor rate of \$5.85/hr was assumed. Ginning was assumed to cost \$0.58/kg (\$2.65/cwt) with no bagging and tie charges and no module transportation costs. A seed price of \$0.18/kg (\$160/ton) was also assumed. The value of cotton from each harvest treatment was determined by averaging the West Texas spot price for cotton from each harvest treatment from 2006 and 2007 from Chapter V (table 22).

Input Variability

A sensitivity analysis was conducted to determine the effect of changes in the input parameters on the breakeven yield for a given harvested area. Sensitivity was calculated as:

$$S = \left| \frac{\Delta Y}{\Delta I} \right| \tag{11}$$

where: S = model sensitivity, and

ΔY = change in breakeven yield per unit change in input parameter I.

The ranges of values for each input parameter to determine a "confidence interval" for breakeven lines are shown in table 38.

Table 38. Ranges of values for NPV model input parameters.

Model Input	Base Scenario			Range
	Picker	**Stripper w/FC**	**Stripper w/o FC**	
Farm				
Row Spacing (cm [in])	76 (30)	76 (30)	76 (30)	76-101 (30-40)
Row Length (m [ft])	915 (3000)	915 (3000)	915 (3000)	±15%
Harvester				
Loan Life (yrs)	7	7	7	None
Loan Rate (% APR)	4.3%	4.3%	4.3%	±2%
Salvage Value (% PP)[a]	45%	45%	45%	±5%
T,H,I (% PP)[a,b]	2%	2%	2%	±0.5%
MSRP ($)	$431,174	$187,303	$169,303[c]	None
Purchase Price (% MSRP)	90%	90%	90%	±5%
Operating Costs				
Diesel ($/gal)	$3.25	$3.25	$3.25	±15%
Labor ($/hr)	$5.85	$5.85	$5.85	±10%
Harvest Aid Applications	1	2	2	None
Harvest Aid Price ($/ap/ha)	$24.70	$24.70	$24.70	±20%
End Row Time (s)	20	20	20	±25%
Speed (kph [mph])	6.1 (3.8)	5.5 (3.4)	5.5 (3.4)	±10%
Fuel Use (L/ha [gal/ac])	26.2 (2.8)	13.1 (1.4)	13.1 (1.4)	±20%
Basket Cap. (kg SC [lbs])[c]	3175 (7000)	1590 (3500)	1520 (3350)	±15%
Dump Time (s)	76	45	45	±25%
Ginning				
Ginning ($/kg SC [$/cwt])[d]	$0.58 ($2.65)	$0.58 ($2.65)	$0.58 ($2.65)	±15%
Lint Turnout (%)	35%	30%	27%	±3%
Seed Turnout (%)	55%	46%	40%	±3%
Lint Price ($/kg [$/cwt])	$1.1758 ($53.38)	$1.1458 ($52.02)	$1.0868 ($49.34)	None
Seed Price ($/kg [$/ton])	$0.18 ($160)	$0.18 ($160)	$0.18 ($160)	±20%

[a] PP = purchase price

[b] T,H,I = taxes, housing, and insurance (taxes = 1%; housing = 0.75%; insurance = 0.25%)

[c] Currently, stripper harvesters are not commercially available without field cleaners

[d] SC = seed cotton

RESULTS AND DISCUSSION

Under the conditions analyzed, the NPV of the stripper system without a field cleaner was always lower than the stripper system with a field cleaner, indicating that stripping without field cleaning is never the most profitable option. However, this analysis does not take into account the risk averted by stripping without field cleaning on days that are too windy to transfer picked or field-cleaned seed cotton from the harvester basket to a boll buggy or module builder. The model also does not place a monetary value on the reduced risk incurred by being able to pick a field earlier than a producer can strip a field or the increased risk incurred through the additional capital investment cost of a picker.

The breakeven yield for a given harvested area decreases as row spacing increases. For example, the breakeven yield between picking and stripping-with-field-cleaning when harvesting 320 ha (800 ac) per machine per year is 5.75 bales/ha (2.33 bales/ac) with the base scenario inputs on 76 cm (30 in.) rows, but it decreases to 5.56 bales/ha (2.25 bales/ac) when on 102 cm (40 in.) rows, assuming the same yield of lint per acre.

The breakeven curve between picking and stripping with a field cleaner is shown in fig. 18. The breakeven curve between picking and stripping without a field cleaner is shown in fig. 19. The black line in both figures represents the breakeven curve for the base scenario while the shaded area represents possible breakeven points within the range of input variables shown in table 38. Areas above the breakeven line represent scenarios in which more profit may be obtained from picking while areas below the breakeven line represent scenarios in which more profit may be obtained by stripper harvesting. Table 39 shows the relative returns per unit area for the picker and stripper-with-field-cleaner systems relative to stripping without field cleaning assuming one machine is used to harvest 243 and 486 ha (600 and 1200 ac), respectively, under the base scenario.

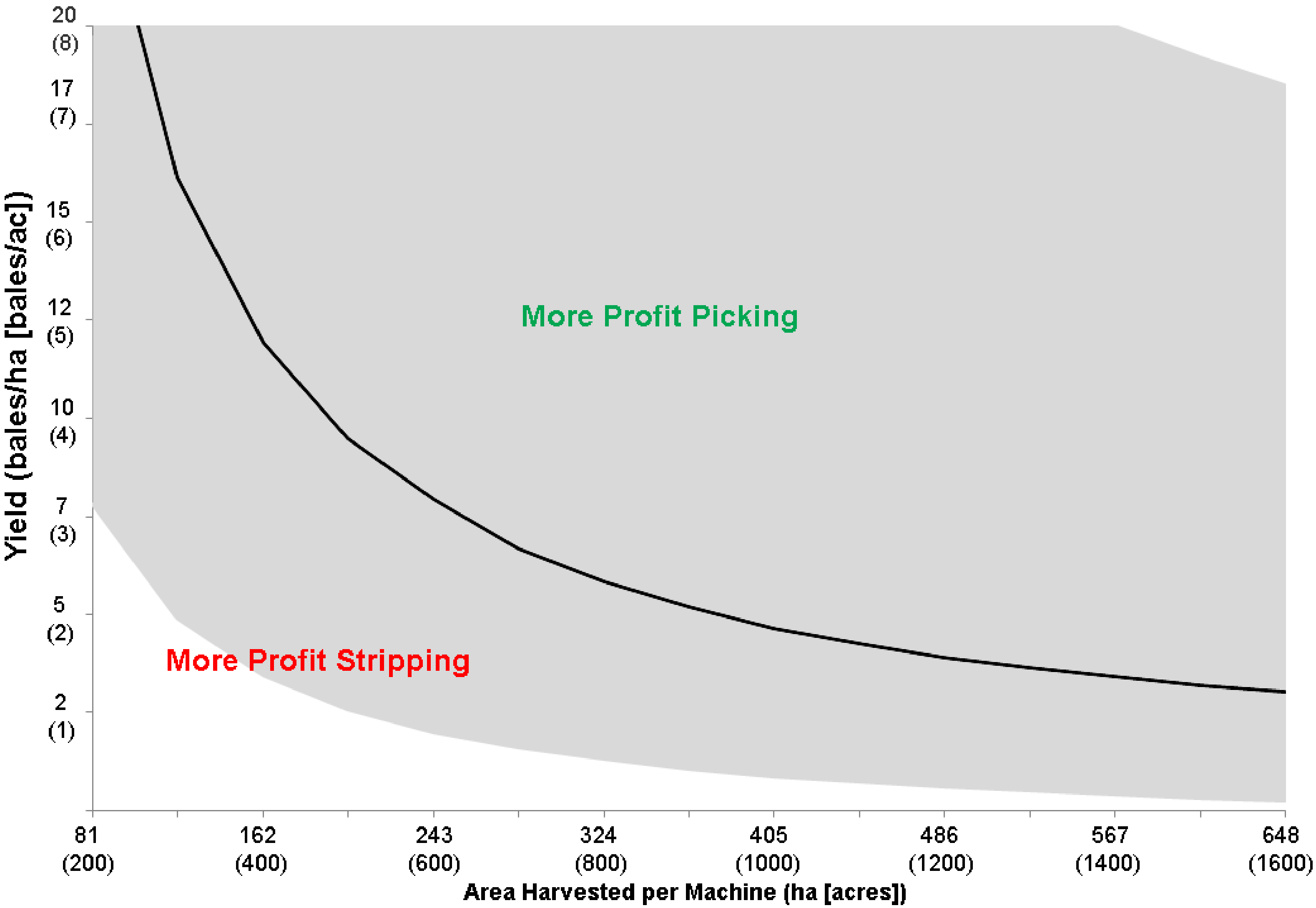


Figure 18. Breakeven curve between picking and stripping with field cleaner from NPV analysis.

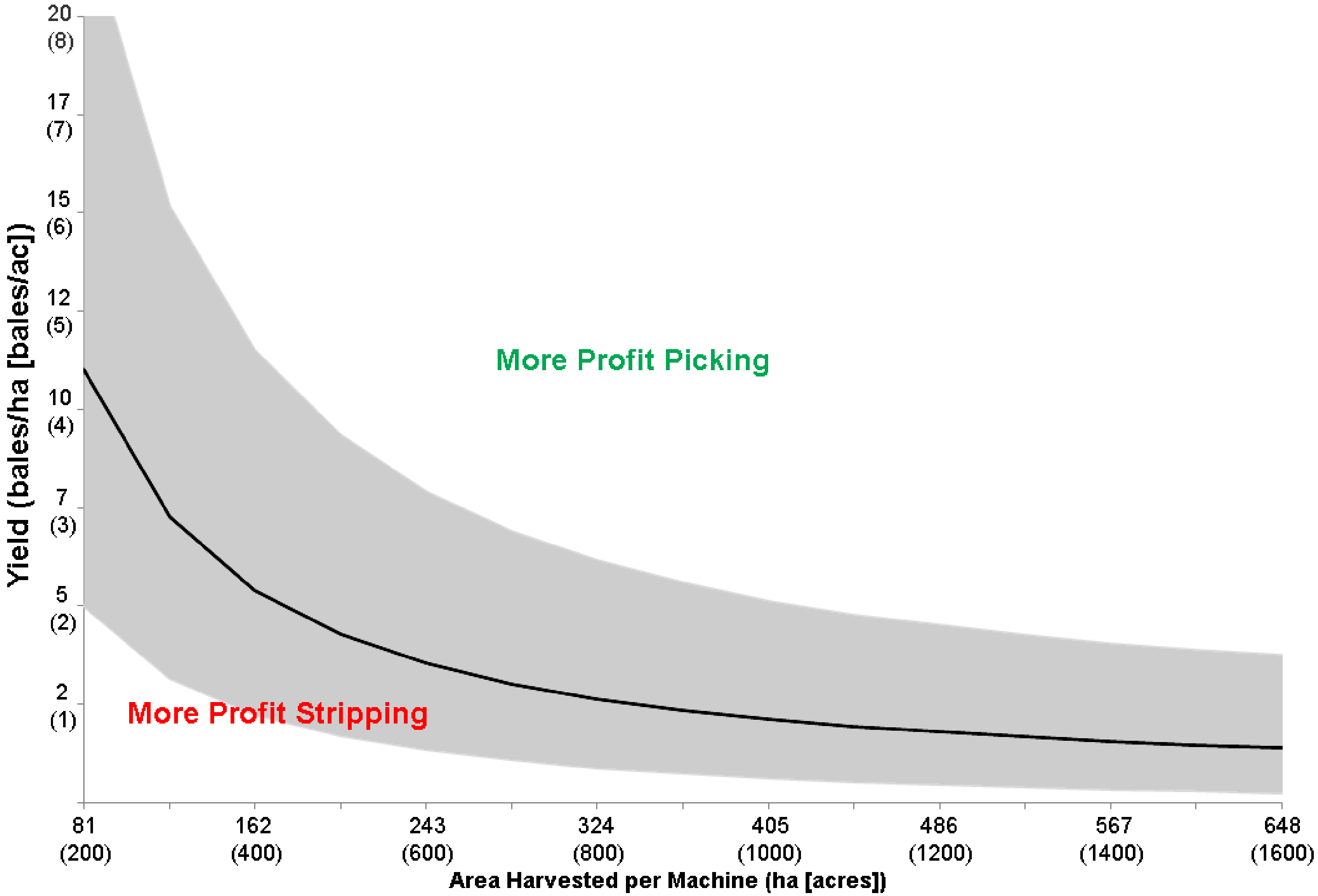


Figure 19. Breakeven curve between picking and stripping without a field cleaner from NPV analysis.

Table 39. Relative returns ($/ha [$/ac]) for various harvest systems.[a]

Yield	Picker	Stripper w/ Field Cleaner	Stripper w/o Field Cleaner
243 ha (600 ac) per Machine			
3.7 (1.5)	$22 ($9)	$393 ($159)	Base
4.9 (2.0)	$281 ($114)	$544 ($220)	Base
6.2 (2.5)	$539 ($218)	$694 ($281)	Base
7.4 (3.0)	$798 ($323)	$845 ($342)	Base
8.7 (3.5)	$1,057 ($428)	$996 ($403)	Base
9.9 (4.0)	$1,316 ($533)	$1,146 ($464)	Base
11.1 (4.5)	$1,575 ($637)	$1,297 ($525)	Base
12.4 (5.0)	$1,834 ($742)	$1,448 ($586)	Base
486 ha (1200 ac) per Machine			
3.7 (1.5)	$396 ($160)	$418 ($169)	Base
4.9 (2.0)	$655 ($265)	$569 ($230)	Base
6.2 (2.5)	$914 ($370)	$719 ($291)	Base
7.4 (3.0)	$1,173 ($475)	$870 ($352)	Base
8.7 (3.5)	$1,432 ($579)	$1,021 ($413)	Base
9.9 (4.0)	$1,690 ($684)	$1,171 ($474)	Base
11.1 (4.5)	$1,949 ($789)	$1,322 ($535)	Base
12.4 (5.0)	$2,208 ($894)	$1,473 ($596)	Base

[a] Assuming the stripper without field cleaner as a base value and with inputs from the Base Scenario.

From figs. 18 and 19, it can be seen that the breakeven yield decreases as the area harvested per machine increases. Furthermore, the yields required for picking to be more profitable than stripping are achievable on the High Plains if a producer has sufficient area to harvest per machine.

The sensitivity of the NPV model to input parameters is shown in table 40 along with the scenarios that would lead to the highest and lowest breakeven yields per unit area. Sensitivity to input variables that differed between stripper and picker treatments was described by the average sensitivity value as calculated by eq. 11.

Table 40. Sensitivity of NPV model to input parameters.

Rank	Model Input	Sensitivity	Max. Breakeven Yield		Min. Breakeven Yield	
1	Diff. Lint Price[a]	7.50	Min. Pick.	Max. Strip.	Max. Pick.	Min. Strip.
2	Seed Turnout	1.71	Min. Pick.	Max. Strip.	Max. Pick.	Min. Strip.
3	Purchase Price	1.35	Max. Pick.	Min. Strip.	Min. Pick.	Max. Strip.
4	Lint Turnout	0.59	Max. Pick.	Min. Strip.	Min. Pick.	Max. Strip.
5	Salvage Value	0.47	Minimize		Maximize	
6	Ginning	0.30	Minimize		Maximize	
7	Loan Rate	0.26	Maximize		Minimize	
8	Speed	0.23	Min. Pick.	Max. Strip.	Max. Pick.	Min. Strip.
9	Harvest Aid Price	0.23	Minimize		Maximize	
10	Fuel Use	0.13	Max. Pick.	Min. Strip.	Min. Pick.	Max. Strip.
11	Row Spacing	0.10	Minimize		Maximize	
12	Diesel	0.09	Maximize		Minimize	
13	Seed Price	0.08	Minimize		Maximize	
14	T,H,I[b]	0.05	Maximize		Minimize	
15	Labor	0.01	Minimize		Maximize	
16	Basket Capacity	0.00	Min. Pick.	Max. Strip.	Max. Pick.	Min. Strip.
17	Dump Time	0.00	Max. Pick.	Min. Strip.	Min. Pick.	Max. Strip.
18	Lint Price	0.00	No effect		No effect	
19	End Row Time	0.00	No effect		No effect	
20	Row Length	0.00	No effect		No effect	

[a] Diff. Lint Price = difference in price between lint harvested with various harvest methods
[b] T,H,I = taxes, housing, and insurance

The NPV model is over four times more sensitive to difference in the price of lint between harvester treatments than any other input parameter. However, the model is relatively insensitive to changes in the price of lint if the price of both picked and stripped lint increase by the same amount. The difference in price between picked and stripped lint is likely to be most influenced by growing conditions (which affect the difference in lint grades) rather than harvest method. The growing conditions in 2007 resulted in high fiber maturity values, which is uncommon. In less ideal years, the difference in grade between picked and stripped cotton is expected to be greater (see 2006 data and Kerby et al., 1986) thus reducing the breakeven yield for a given harvested area.

Seed turnout and harvester purchase price, which are the second and third most influential model inputs, are substantially impacted by harvest method. The model is relatively insensitive to changes in harvester basket capacity, dump time, the time spent on the turn row, and row length within the ranges analyzed.

CONCLUSIONS

A breakeven analysis based on NPV was conducted to compare picker-based and stripper-based harvest systems with and without field cleaners. Under no conditions analyzed was the NPV of a stripper system without a field cleaner greater than a stripper system with a field cleaner. Breakeven curves relating yield to harvested-area-per-machine were developed to compare picker-based systems with both stripper-based systems. The breakeven yield decreases as the area harvested per machine increases. Furthermore, the yields required for picking to be more profitable than stripping are achievable on the High Plains if a producer has sufficient area to harvest per machine.

The results of a sensitivity analysis of the NPV model demonstrate that the model is most sensitive to changes in the difference between picked and stripped lint, which is most influenced by growing conditions rather than harvest method. The model is relatively insensitive to level changes in the price of lint. The model is relatively sensitive to changes in seed turnout and machinery purchase price. It is expected that the breakeven yield for a given harvested area will decrease with more adverse growing conditions (leading to less mature fibers) and increase with more ideal growing conditions (leading to more mature fibers).

CHAPTER VIII
SUMMARY AND CONCLUSIONS

Harvest machinery represents a substantial expenditure for cotton producers on the High Plains and throughout the United States. When selecting a harvest system, capital investment and maintenance costs must be considered within a framework that includes analysis of the timeliness and efficiency of harvest, the quality of fibers harvested, and the needs of the textile mill that purchases a producer's cotton.

The performance of picker and stripper harvesters on irrigated cotton on the High Plains of Texas was evaluated on the basis of harvest efficiency, time-in-motion, the cost of ginning, fiber and yarn quality, and economic returns. Harvester performance data and seed cotton samples were collected from four farms with varying soil and weather conditions across the High Plains over two harvest seasons.

Harvest efficiency was measured to determine the amount of seed cotton left in the field by each machine. While stripper harvesters demonstrated higher harvest efficiencies, the cotton left in the field by the picker was of lower quality and often reduced the value of the lint harvested per unit area.

Time-in-motion data were collected to characterize the time required for each operation of harvest, including time spent on the row harvesting, transferring seed cotton to a boll buggy, and turning at the end of the row. Time-in-motion data were highly variable and dependent on the support equipment available, such as the number of boll buggies and module builders supporting each harvester. In general, pickers were able to travel faster through the field in high yielding cotton, especially when the field cleaner was the bottleneck in harvester operations. However, as yield decreased, the speed of the stripper during harvest superseded that of the picker, especially when bypassing the field cleaner. However, the substantially smaller basket capacity of the stripper required more frequent dumping, which dramatically impacted the productivity rate of the stripper systems.

The cost of ginning picked and stripped (field-cleaned) cotton was compared based on ginning schedules from three High Plains gins and measured lint turnouts. On average, it cost the producer $4.76 per bale more to gin stripped-and-field-cleaned cotton compared to picked cotton due to the higher foreign matter content of the seed cotton. Differences were seen in the content of burs, sticks, leaf, and pin trash in seed cotton as a function of harvest method. The increased foreign matter content also led to increased utility consumption by the gin while processing stripped cotton compared to picked cotton.

Fiber quality of cottons from each harvest treatment was analyzed with HVI and AFIS. In 2006, when fibers were immature, micronaire, length, and length uniformity were better for picker harvested cotton than for stripped cotton leading to a higher loan value and average sale price for the producer. In 2007, when growing conditions were better and fibers were more mature, differences in fiber quality parameters between picked and stripped cottons were less pronounced leading to less discrepancy in the value of cotton harvested. However, in 2007, differences in nep counts, short fiber content (SFC), and visible foreign matter between harvest treatments were distinguishable. These results support the findings of Kerby et al. (1986) that differences in fiber quality between harvest treatments are more pronounced in years of adverse growing conditions.

The results of this study indicate that, by using picker harvesters, producers may realize greater fiber quality and lint value, but the magnitude of those differences may be a function of growing conditions and/or fiber maturity. Varietal differences also played a large role in determining fiber properties, but in 2007, no differences were seen in the value of harvested lint as a result of these differences.

Yarn quality indices were analyzed to determine differences in ring-spun yarns from cottons harvested with picker and stripper harvesters. Yarn quality was compared and regression analyses were conducted to determine relationships between fiber and yarn properties. Few differences were detected in carded yarn quality between harvest treatments, while more pronounced differences favoring picked cotton were seen in carded-and-combed yarns. During both 2006 and 2007, the evenness of carded-and-combed yarns was improved by picking over stripping as measured by yarn CV, thick places, and neps (+200%), and the hairiness of carded yarns was reduced by picking. In 2007, when fibers were more mature, picking improved the count strength product (CSP), tenacity, and nep counts of carded yarns. Noils, which were correlated to SFC, were also reduced by picking. In 2007, variety had a greater impact on yarn quality than harvest treatment.

Results of regression analyses were consistent with the findings of previous investigations with regards to CSP, yarn elongation, and carded yarn evenness. Contrary to previous studies, no significant relationships were detected between yarn tenacity and fiber strength or between fiber length and yarn hairiness.

The results of the harvester performance and lint quality evaluations were used to compare the net present value (NPV) of picker and stripper harvesters under a range of conditions. A breakeven analysis based on NPV was conducted to compare the value of various harvest systems within the production system. Under no conditions analyzed was the NPV of a stripper system without a field cleaner greater than a stripper system with a field cleaner. Breakeven curves relating yield to harvested-area-per-machine were developed to compare picker-based systems with both stripper-based systems. The breakeven yield between picking and stripping decreases as the area harvested per machine increases. The yields required for picking to be more profitable than stripping are achievable on the High Plains if a producer has sufficient area to harvest per machine.

The results of a sensitivity analysis of the NPV model demonstrate that the model is most sensitive to changes in the difference between picked and stripped lint, which is most influenced by growing conditions. The model is relatively insensitive to level changes in the price of lint. The model is relatively sensitive to changes in seed turnout and machinery purchase price. It is expected that the breakeven yield for a given harvested area will decrease with more adverse growing conditions and increase with more ideal growing conditions.

With increased yields in the High Plains and increased demands from textile mills for high fiber quality, picker harvesting is a reasonable and potentially profitable alternative for High Plains producers. The potential profitability of a picker-based system on the High Plains depends on the area to be harvested per machine and price differential between picked and stripped cotton, which expands as growing conditions become more adverse to cotton fiber maturation.

FUTURE WORK

Based on the availability of funding, more data will be collected to further refine the results of this work. In addition to increasing the sample size of data, the following have been identified future work in this area:

1. Fiber quality parameters measured by HVI systems and reported as part of the USDA-AMS cotton classification system provide textile mills with a substantial amount of information regarding the type of cotton they are purchasing, but these parameters are insufficient to repeatably predict the quality of yarn that will result from processing a bale of given HVI quality parameters. Research could be conducted to determine if differences exist in yarn quality and spinning performance between bales of cotton that are picker harvested versus stripper harvested but have the same HVI classification data. In this manner, it would be possible to determine if there is reason to form a marketing pool for picked High Plains cotton that could be sold for a premium based on the spinnability of cotton in the pool.
2. Because of differences in basket capacity between picker and stripper harvesters, in general, more support equipment such as boll buggies and module builders are required to support stripper harvesters if they are to harvest as efficiently as possible. However, larger boll buggies are needed to receive a full basket of picked seed cotton compared to those required for stripper harvesting. The economic model may be expanded to include

support equipment in order to produce a more comprehensive economic comparison between harvest systems.

3. With the recent advent of on-harvester module builders for pickers by both major manufacturers of cotton harvesters, a new layer of data analysis is possible. The economic model may be expanded to compare stripper-based systems with on-board module building systems.

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APPENDIX A

SEED COTTON MOISTURE CONTENT DATA

Table 41. Average seed cotton moisture content data.

Site	Treatment	Variety	Rep	Moisture Content ($\%_{wb}$)
1	Picker	ST 4554 B2RF	1	6.11
1	Picker	ST 4554 B2RF	2	7.36
1	Picker	ST 4554 B2RF	3	7.42
1	Stripper with Field Cleaner	ST 4554 B2RF	1	6.63
1	Stripper with Field Cleaner	ST 4554 B2RF	2	7.02
1	Stripper with Field Cleaner	ST 4554 B2RF	3	6.55
1	Stripper without Field Cleaner	ST 4554 B2RF	1	6.10
1	Stripper without Field Cleaner	ST 4554 B2RF	2	6.27
1	Stripper without Field Cleaner	ST 4554 B2RF	3	5.88
2	Picker	FM 9063 B2RF	1	4.64
2	Picker	FM 9063 B2RF	2	4.84
2	Picker	FM 9063 B2RF	3	4.60
3	Picker	FM 9058 F	1	5.65
3	Picker	FM 9058 F	2	5.30
3	Picker	FM 9058 F	3	3.3
3	Picker	FM 9063 B2RF	1	5.54
3	Picker	FM 9063 B2RF	2	5.45
3	Picker	FM 9063 B2RF	3	4.79
3	Picker	PHY 485 WRF	1	5.78
3	Picker	PHY 485 WRF	2	5.34
3	Picker	PHY 485 WRF	3	5.37
3	Picker	ST 4554 B2RF	1	5.60
3	Picker	ST 4554 B2RF	2	5.38
3	Picker	ST 4554 B2RF	3	4.74
3	Stripper with Field Cleaner	FM 9058 F	1	5.15
3	Stripper with Field Cleaner	FM 9058 F	2	4.94
3	Stripper with Field Cleaner	FM 9058 F	3	4.38
3	Stripper with Field Cleaner	FM 9063 B2RF	1	5.11
3	Stripper with Field Cleaner	FM 9063 B2RF	2	4.74
3	Stripper with Field Cleaner	FM 9063 B2RF	3	4.19
3	Stripper with Field Cleaner	PHY 485 WRF	1	4.67
3	Stripper with Field Cleaner	PHY 485 WRF	2	4.85
3	Stripper with Field Cleaner	PHY 485 WRF	3	4.57
3	Stripper with Field Cleaner	ST 4554 B2RF	1	4.48
3	Stripper with Field Cleaner	ST 4554 B2RF	2	4.68
3	Stripper with Field Cleaner	ST 4554 B2RF	3	4.31
4	Picker	FM 9058 F	1	5.05
4	Picker	FM 9058 F	3	5.80
4	Picker	FM 9063 B2RF	1	4.10
4	Picker	FM 9063 B2RF	3	5.15
4	Picker	PHY 485 WRF	1	4.96
4	Picker	PHY 485 WRF	3	5.33
4	Picker	ST 4554 B2RF	1	4.59
4	Picker	ST 4554 B2RF	3	5.56
4	Stripper with Field Cleaner	FM 9058 F	1	5.67
4	Stripper with Field Cleaner	FM 9058 F	2	6.51
4	Stripper with Field Cleaner	FM 9058 F	3	6.61
4	Stripper with Field Cleaner	FM 9063 B2RF	1	4.98

Table 41 Continued.

Site	Treatment	Variety	Rep	Moisture Content (%$_{wb}$)
4	Stripper with Field Cleaner	FM 9063 B2RF	2	6.44
4	Stripper with Field Cleaner	FM 9063 B2RF	3	5.56
4	Stripper with Field Cleaner	PHY 485 WRF	1	5.84
4	Stripper with Field Cleaner	PHY 485 WRF	2	6.55
4	Stripper with Field Cleaner	PHY 485 WRF	3	6.00
4	Stripper with Field Cleaner	ST 4554 B2RF	1	5.65
4	Stripper with Field Cleaner	ST 4554 B2RF	2	6.41
4	Stripper with Field Cleaner	ST 4554 B2RF	3	5.58

APPENDIX B

PLANT HEIGHT DATA

Table 42. Average plant height data.

Site	Treatment	Variety	Rep	Plant Height (cm)
2	Picker	FM 9063 B2RF	1	76.5
2	Picker	FM 9063 B2RF	2	76.8
2	Picker	FM 9063 B2RF	3	63.3
2	Picker	FM 9063 B2RF	4	72.7
2	Picker	FM 9063 B2RF	5	70.9
3	Picker	FM 9058 F	1	57.2
3	Picker	FM 9058 F	2	58.3
3	Picker	FM 9058 F	3	58.9
3	Picker	FM 9063 B2RF	1	53.7
3	Picker	FM 9063 B2RF	2	55.9
3	Picker	FM 9063 B2RF	3	55.2
3	Picker	PHY 485 WRF	1	66.7
3	Picker	PHY 485 WRF	2	63.6
3	Picker	PHY 485 WRF	3	59.2
3	Picker	ST 4554 B2RF	1	56.3
3	Picker	ST 4554 B2RF	2	53.4
3	Picker	ST 4554 B2RF	3	51.5
4	Picker	FM 9058 F	1	85.2
4	Picker	FM 9058 F	2	75.8
4	Picker	FM 9058 F	3	84.1
4	Picker	FM 9063 B2RF	1	70.6
4	Picker	FM 9063 B2RF	2	76.5
4	Picker	FM 9063 B2RF	3	70.3
4	Picker	PHY 485 WRF	1	82.5
4	Picker	PHY 485 WRF	2	105.1
4	Picker	PHY 485 WRF	3	79.8
4	Picker	ST 4554 B2RF	1	76.2
4	Picker	ST 4554 B2RF	2	78.3
4	Picker	ST 4554 B2RF	3	76.8
4	Stripper with Field Cleaner	FM 9058 F	1	78.6
4	Stripper with Field Cleaner	FM 9058 F	2	77.8
4	Stripper with Field Cleaner	FM 9058 F	3	85.2
4	Stripper with Field Cleaner	FM 9063 B2RF	1	69.8
4	Stripper with Field Cleaner	FM 9063 B2RF	2	76.8
4	Stripper with Field Cleaner	FM 9063 B2RF	3	72.6
4	Stripper with Field Cleaner	PHY 485 WRF	1	91.3
4	Stripper with Field Cleaner	PHY 485 WRF	2	93.7
4	Stripper with Field Cleaner	PHY 485 WRF	3	75.5
4	Stripper with Field Cleaner	ST 4554 B2RF	1	73.3
4	Stripper with Field Cleaner	ST 4554 B2RF	2	90.1
4	Stripper with Field Cleaner	ST 4554 B2RF	3	71.0

APPENDIX C

HARVEST EFFICIENCY DATA

Table 43. Harvest efficiency data.

Site	Treatment	Variety	Rep	Left on Plant (%)	Knocked Off (%)	Harvest Efficiency (%)
1	Picker	ST 4554 B2RF	1	5.11	15.40	79.49
1	Picker	ST 4554 B2RF	2	0.80	8.54	90.66
1	Picker	ST 4554 B2RF	3	1.70	7.55	90.74
1	Picker	ST 4554 B2RF	4	0.02	6.14	93.83
1	Picker	ST 4554 B2RF	5	1.85	3.38	94.77
1	Stripper w/ FC	ST 4554 B2RF	1	0.72	1.60	97.69
1	Stripper w/ FC	ST 4554 B2RF	2	0.00	7..88	92.12
1	Stripper w/ FC	ST 4554 B2RF	3	0.75	0.62	98.63
1	Stripper w/ FC	ST 4554 B2RF	4	0.00	0.00	100.00
1	Stripper w/ FC	ST 4554 B2RF	5	3.14	2.43	94.43
1	Stripper w/o FC	ST 4554 B2RF	1	0.15	1.84	98.01
1	Stripper w/o FC	ST 4554 B2RF	2	0.42	1.06	98.52
1	Stripper w/o FC	ST 4554 B2RF	3	0.00	0.69	99.31
1	Stripper w/o FC	ST 4554 B2RF	4	0.00	1.90	98.10
1	Stripper w/o FC	ST 4554 B2RF	5	0.00	1.64	98.36
2	Picker	FM 9063 B2RF	1	2.68	1.34	95.98
2	Picker	FM 9063 B2RF	2	0.33	2.01	97.65
2	Picker	FM 9063 B2RF	3	0.13	0.53	99.34
2	Picker	FM 9063 B2RF	4	0.97	1.06	97.97
2	Picker	FM 9063 B2RF	5	0.44	0.73	98.83
3	Picker	FM 9058 F	1	1.27	3.24	95.49
3	Picker	FM 9058 F	2	0.30	0.65	99.04
3	Picker	FM 9058 F	3	0.66	2.80	96.54
3	Picker	FM 9063 B2RF	1	1.28	1.78	96.94
3	Picker	FM 9063 B2RF	2	1.86	2.30	95.85
3	Picker	FM 9063 B2RF	3	1.36	2.59	96.05
3	Picker	PHY 485 WRF	1	0.29	0.83	98.89
3	Picker	PHY 485 WRF	2	0.65	2.70	96.65
3	Picker	PHY 485 WRF	3	0.14	8.03	91.84
3	Picker	ST 4554 B2RF	1	1.43	3.76	94.81
3	Picker	ST 4554 B2RF	2	0.65	1.81	97.54
3	Picker	ST 4554 B2RF	3	0.44	3.47	96.09
3	Stripper w/ FC	FM 9058 F	1	0.00	1.56	98.44
3	Stripper w/ FC	FM 9058 F	2	1.46	2.89	95.65
3	Stripper w/ FC	FM 9058 F	3	0.02	0.49	99.49
3	Stripper w/ FC	FM 9063 B2RF	1	0.00	1.00	99.00
3	Stripper w/ FC	FM 9063 B2RF	2	0.00	0.74	99.26
3	Stripper w/ FC	FM 9063 B2RF	3	0.00	1.17	98.83
3	Stripper w/ FC	PHY 485 WRF	1	0.00	0.27	99.73
3	Stripper w/ FC	PHY 485 WRF	2	0.00	1.46	98.54
3	Stripper w/ FC	PHY 485 WRF	3	0.00	1.04	98.96
3	Stripper w/ FC	ST 4554 B2RF	1	0.00	3.55	96.45
3	Stripper w/ FC	ST 4554 B2RF	2	0.00	5.20	94.80
3	Stripper w/ FC	ST 4554 B2RF	3	0.31	6.10	93.59
4	Picker	FM 9058 F	1	0.91	4.80	94.29
4	Picker	FM 9058 F	2	2.12	5.36	92.51
4	Picker	FM 9058 F	3	1.86	1.87	96.27

Table 43 Continued.

Site	Treatment	Variety	Rep			
4	Picker	FM 9063 B2RF	1	0.00	1.95	98.05
4	Picker	FM 9063 B2RF	2	0.79	3.07	96.14
4	Picker	FM 9063 B2RF	3	0.11	4.12	95.77
4	Picker	PHY 485 WRF	1	1.02	4.21	94.77
4	Picker	PHY 485 WRF	2	0.47	5.12	94.41
4	Picker	PHY 485 WRF	3	0.26	2.19	97.56
4	Picker	ST 4554 B2RF	1	0.35	3.73	95.92
4	Picker	ST 4554 B2RF	2	1.54	11.58	86.88
4	Picker	ST 4554 B2RF	3	0.37	3.05	96.59
4	Stripper w/ FC	FM 9058 F	1	0.00	0.13	99.87
4	Stripper w/ FC	FM 9058 F	2	0.00	0.11	99.89
4	Stripper w/ FC	FM 9058 F	3	0.15	2.94	96.90
4	Stripper w/ FC	FM 9063 B2RF	1	0.00	1.21	98.79
4	Stripper w/ FC	FM 9063 B2RF	2	0.00	8.41	91.59
4	Stripper w/ FC	FM 9063 B2RF	3	0.04	0.33	99.63
4	Stripper w/ FC	PHY 485 WRF	1	0.00	1.58	98.42
4	Stripper w/ FC	PHY 485 WRF	2	0.00	0.45	99.55
4	Stripper w/ FC	PHY 485 WRF	3	0.00	1.24	98.76
4	Stripper w/ FC	ST 4554 B2RF	1	0.08	2.79	97.13
4	Stripper w/ FC	ST 4554 B2RF	2	0.03	1.03	98.94
4	Stripper w/ FC	ST 4554 B2RF	3	0.00	1.73	98.27

APPENDIX D
FRACTIONATION ANALYSIS DATA

Table 44. Fractionation analysis data.

Site	Treatment	Variety	Rep	Burs (%)	Sticks (%)	Leaf (%)	Pin Trash (%)	Motes (%)	Total Foreign Matter (%)
1	Picker	ST 4554 B2RF	1	2.23	0.43	1.98	0.37	0.06	5.08
1	Picker	ST 4554 B2RF	2	2.75	0.49	2.39	0.31	0.06	6.00
1	Picker	ST 4554 B2RF	3	1.93	0.36	1.99	0.36	0.06	4.70
1	Picker	ST 4554 B2RF	4	2.39	0.63	2.71	0.38	0.19	6.36
1	Picker	ST 4554 B2RF	5	1.17	0.47	2.05	0.23	0.06	4.05
1	Stripper w/ FC	ST 4554 B2RF	1	11.79	1.71	3.77	0.53	0.06	17.91
1	Stripper w/ FC	ST 4554 B2RF	2	9.43	1.81	2.99	0.29	0.00	14.52
1	Stripper w/ FC	ST 4554 B2RF	3	10.60	1.36	4.91	0.24	0.06	17.29
1	Stripper w/ FC	ST 4554 B2RF	4	10.13	1.51	3.40	0.19	0.06	15.35
1	Stripper w/ FC	ST 4554 B2RF	5	10.27	0.86	3.73	0.17	0.06	15.09
1	Stripper w/o FC	ST 4554 B2RF	1	18.94	1.30	3.60	0.31	0.06	24.22
1	Stripper w/o FC	ST 4554 B2RF	2	27.48	1.79	3.11	0.18	0.06	32.68
1	Stripper w/o FC	ST 4554 B2RF	3	22.01	1.79	4.04	0.31	0.00	28.15
1	Stripper w/o FC	ST 4554 B2RF	4	17.35	3.48	3.70	0.28	0.00	24.81
1	Stripper w/o FC	ST 4554 B2RF	5	13.81	1.79	3.45	0.24	0.00	19.29
3	Picker	FM 9058 F	1	1.10	0.32	1.06	0.32	0.00	2.80
3	Picker	FM 9058 F	2	2.40	0.46	0.88	0.51	0.00	4.24
3	Picker	FM 9058 F	3	0.86	0.53	0.74	0.92	0.00	3.05
3	Picker	FM 9063 B2RF	1	1.39	0.33	1.13	0.36	0.00	3.20
3	Picker	FM 9063 B2RF	2	1.08	0.52	0.89	0.36	0.00	2.85
3	Picker	FM 9063 B2RF	3	1.98	0.06	0.90	0.52	0.00	6.02
3	Picker	PHY 485 WRF	1	0.87	0.42	0.83	0.51	0.00	2.63
3	Picker	PHY 485 WRF	2	1.31	0.60	1.07	0.78	0.00	3.76
3	Picker	PHY 485 WRF	3	1.39	0.27	0.98	0.79	0.00	3.44
3	Picker	ST 4554 B2RF	1	1.61	0.88	2.88	1.11	0.00	6.47
3	Picker	ST 4554 B2RF	2	1.00	0.35	0.86	0.65	0.00	2.86
3	Picker	ST 4554 B2RF	3	1.77	0.81	0.74	0.59	0.00	3.91
3	Stripper w/ FC	FM 9058 F	1	7.02	2.49	4.19	1.44	0.00	15.28
3	Stripper w/ FC	FM 9058 F	2	8.35	2.07	3.33	1.16	0.00	14.90
3	Stripper w/ FC	FM 9058 F	3	10.44	2.68	3.08	0.70	0.00	18.81
3	Stripper w/ FC	FM 9063 B2RF	1	11.81	2.17	2.28	1.14	0.00	18.30
3	Stripper w/ FC	FM 9063 B2RF	2	8.89	2.26	2.85	1.65	0.00	15.65
3	Stripper w/ FC	FM 9063 B2RF	3	9.97	2.49	3.71	1.19	0.00	17.60

Table 44 Continued.

Site	Treatment	Variety	Rep	Burs (%)	Sticks (%)	Leaf (%)	Pin Trash (%)	Motes (%)	Total Foreign Matter (%)
3	Stripper w/ FC	PHY 485 WRF	1	18.50	3.00	3.95	1.55	0.00	27.01
3	Stripper w/ FC	PHY 485 WRF	2	11.29	3.44	3.37	1.40	0.00	19.50
3	Stripper w/ FC	PHY 485 WRF	3	7.83	3.39	3.97	2.36	0.00	17.55
3	Stripper w/ FC	ST 4554 B2RF	1	13.25	4.08	3.74	1.44	0.00	22.51
3	Stripper w/ FC	ST 4554 B2RF	2	6.74	3.48	2.81	1.75	0.00	14.77
3	Stripper w/ FC	ST 4554 B2RF	3	6.74	2.23	3.23	1.65	0.00	13.84
4	Picker	FM 9058 F	1	1.91	0.85	1.87	1.25	0.00	5.88
4	Picker	FM 9058 F	2	2.09	0.53	1.75	0.95	0.00	5.32
4	Picker	FM 9058 F	3	2.22	0.82	1.87	1.02	0.00	5.92
4	Picker	FM 9063 B2RF	1	2.91	0.32	1.18	0.70	0.00	5.10
4	Picker	FM 9063 B2RF	2	0.99	0.98	2.47	0.82	0.00	5.26
4	Picker	FM 9063 B2RF	3	1.53	0.59	3.43	1.09	0.00	6.64
4	Picker	PHY 485 WRF	1	2.27	1.19	1.17	0.90	0.00	5.54
4	Picker	PHY 485 WRF	2	2.39	0.93	1.95	1.24	0.00	6.51
4	Picker	PHY 485 WRF	3	3.91	1.16	2.19	1.18	0.00	8.44
4	Picker	ST 4554 B2RF	1	1.44	0.73	1.75	1.23	0.00	5.15
4	Picker	ST 4554 B2RF	2	1.46	1.14	2.24	1.27	0.00	6.11
4	Picker	ST 4554 B2RF	3	2.60	0.95	2.27	1.45	0.00	7.27
4	Stripper w/ FC	FM 9058 F	1	9.48	3.12	3.04	1.30	0.00	16.94
4	Stripper w/ FC	FM 9058 F	2	6.43	2.02	3.46	1.01	0.00	12.91
4	Stripper w/ FC	FM 9058 F	3	8.83	3.16	5.54	1.62	0.00	19.15
4	Stripper w/ FC	FM 9063 B2RF	1	8.77	2.41	3.26	1.01	0.00	15.45
4	Stripper w/ FC	FM 9063 B2RF	2	7.93	3.74	3.45	1.43	0.00	16.55
4	Stripper w/ FC	FM 9063 B2RF	3	8.09	4.47	8.82	2.28	0.00	23.66
4	Stripper w/ FC	PHY 485 WRF	1	5.92	3.70	1.85	1.04	0.00	12.52
4	Stripper w/ FC	PHY 485 WRF	2	10.18	5.72	2.50	1.17	0.00	19.56
4	Stripper w/ FC	PHY 485 WRF	3	6.68	3.97	2.96	1.46	0.00	15.06
4	Stripper w/ FC	ST 4554 B2RF	1	8.23	2.78	4.07	1.44	0.00	16.51
4	Stripper w/ FC	ST 4554 B2RF	2	5.12	4.38	4.40	1.67	0.00	15.57
4	Stripper w/ FC	ST 4554 B2RF	3	6.08	2.98	3.06	1.37	0.00	13.49

APPENDIX E

TURNOUT DATA

Table 45. Turnout data.

Site	Treatment	Variety	Rep	Lint Turnout (%)
1	Picker	ST 4554 B2RF	M[a]	35.6
1	Stripper w/ FC	ST 4554 B2RF	M[a]	30.2
1	Stripper w/o FC	ST 4554 B2RF	M[a]	26.6
3	Picker	FM 9058 F	1	39.5
3	Picker	FM 9058 F	2	38.6
3	Picker	FM 9058 F	3	40.7
3	Picker	FM 9063 B2RF	1	36.1
3	Picker	FM 9063 B2RF	2	36.3
3	Picker	FM 9063 B2RF	3	35.8
3	Picker	PHY 485 WRF	1	33.0
3	Picker	PHY 485 WRF	2	31.1
3	Picker	PHY 485 WRF	3	35.3
3	Picker	ST 4554 B2RF	1	36.2
3	Picker	ST 4554 B2RF	2	35.2
3	Picker	ST 4554 B2RF	3	35.8
3	Stripper w/ FC	FM 9058 F	1	29.6
3	Stripper w/ FC	FM 9058 F	2	33.9
3	Stripper w/ FC	FM 9058 F	3	31.2
3	Stripper w/ FC	FM 9063 B2RF	1	28.8
3	Stripper w/ FC	FM 9063 B2RF	2	29.7
3	Stripper w/ FC	FM 9063 B2RF	3	29.4
3	Stripper w/ FC	PHY 485 WRF	1	27.5
3	Stripper w/ FC	PHY 485 WRF	2	27.8
3	Stripper w/ FC	PHY 485 WRF	3	27.4
3	Stripper w/ FC	ST 4554 B2RF	1	28.1
3	Stripper w/ FC	ST 4554 B2RF	2	28.5
3	Stripper w/ FC	ST 4554 B2RF	3	28.8
4	Picker	FM 9058 F	1	36.5
4	Picker	FM 9058 F	2	37.5
4	Picker	FM 9058 F	3	37.3
4	Picker	FM 9063 B2RF	1	35.4
4	Picker	FM 9063 B2RF	2	34.2
4	Picker	FM 9063 B2RF	3	34.3
4	Picker	PHY 485 WRF	1	32.6
4	Picker	PHY 485 WRF	2	30.5
4	Picker	PHY 485 WRF	3	33.8
4	Picker	ST 4554 B2RF	1	35.9
4	Picker	ST 4554 B2RF	2	33.4
4	Picker	ST 4554 B2RF	3	34.2
4	Stripper w/ FC	FM 9058 F	1	31.5
4	Stripper w/ FC	FM 9058 F	2	30.1
4	Stripper w/ FC	FM 9058 F	3	32.4
4	Stripper w/ FC	FM 9063 B2RF	1	29.3
4	Stripper w/ FC	FM 9063 B2RF	2	29.9
4	Stripper w/ FC	FM 9063 B2RF	3	31.8
4	Stripper w/ FC	PHY 485 WRF	1	24.6
4	Stripper w/ FC	PHY 485 WRF	2	29.6

[a] Data represents a module average.

Table 45 Continued.

Site	Treatment	Variety	Rep	Lint Turnout (%)
4	Stripper w/ FC	PHY 485 WRF	3	29.5
4	Stripper w/ FC	ST 4554 B2RF	1	32.1
4	Stripper w/ FC	ST 4554 B2RF	2	30.4
4	Stripper w/ FC	ST 4554 B2RF	3	29.9

APPENDIX F
HVI ANALYSIS DATA

Table 46. HVI data.

Site	Treatment	Variety	Rep	Mic.	UHML[a] (cm)	Unif. (%)	Strength (g/tex)	Elong. (%)	Rd	+b	Color Grade	Leaf
1	Picker	ST 4554 B2RF	1	3.6	2.84	81.3	28.6	8.3	81.8	8.3	21-1	2
1	Picker	ST 4554 B2RF	2	3.4	2.82	80.4	26.1	8.7	81.4	8.0	21-1	2
1	Picker	ST 4554 B2RF	3	3.6	2.77	79.8	27.2	8.4	81.6	7.9	21-2	2
1	Picker	ST 4554 B2RF	4	3.4	2.84	79.9	26.4	8.1	81.5	8.1	21-1	2
1	Stripper w/ FC	ST 4554 B2RF	1	3.2	2.77	79.5	24.8	9.2	81.2	8.4	21-1	2
1	Stripper w/ FC	ST 4554 B2RF	2	3.3	2.77	79.6	26.9	8.5	81.1	8.7	21-1	2
1	Stripper w/ FC	ST 4554 B2RF	3	3.1	2.79	79.3	27.2	8.7	80.7	8.2	21-1	3
1	Stripper w/ FC	ST 4554 B2RF	4	3.3	2.77	79.1	25.9	8.5	81.4	8.5	21-1	3
1	Stripper w/o FC	ST 4554 B2RF	1	3.2	2.77	78.8	26.1	8.8	80.9	8.6	21-1	2
1	Stripper w/o FC	ST 4554 B2RF	2	3.2	2.79	79.6	26.2	8.2	80.4	8.9	21-1	2
1	Stripper w/o FC	ST 4554 B2RF	3	2.9	2.79	78.9	26.8	8.4	80.5	8.9	21-1	3
1	Stripper w/o FC	ST 4554 B2RF	4	3.4	2.79	79.6	27.1	8.6	81.8	8.2	21-1	2
3	Picker	FM 9058 F	1	4.6	2.84	80.6	29.0	7.2	81.5	7.8	21-2	1
3	Picker	FM 9058 F	2	4.1	2.97	80.8	29.9	7.3	83.2	7.4	21-1	1
3	Picker	FM 9058 F	3	3.6	2.97	80.8	28.4	7.2	82.8	7.5	21-1	1
3	Picker	FM 9063 B2RF	1	4.2	3.02	81.1	30.3	7.8	83.2	7.4	21-1	1
3	Picker	FM 9063 B2RF	2	4.3	3.02	80.9	31.8	7.5	84.2	7.2	21-1	1
3	Picker	FM 9063 B2RF	3	4.0	3.05	81.3	31.3	7.5	83.7	7.5	21-1	1
3	Picker	PHY 485 WRF	1	4.4	2.87	82.9	29.0	10.0	78.8	8.7	21-2	1
3	Picker	PHY 485 WRF	2	4.0	2.90	83.0	29.2	9.9	79.4	9.0	21-1	3
3	Picker	PHY 485 WRF	3	4.2	2.90	82.2	29.1	9.7	79.8	8.6	21-1	2
3	Picker	ST 4554 B2RF	1	4.1	2.90	81.8	30.6	9.9	80.8	8.7	21-1	1
3	Picker	ST 4554 B2RF	2	4.0	2.84	81.4	30.6	9.9	80.6	8.8	21-1	1
3	Picker	ST 4554 B2RF	3	3.9	2.87	81.5	28.5	10.3	81.5	8.6	21-1	1
3	Stripper w/ FC	FM 9058 F	1	4.8	2.69	79.0	28.2	7.3	81.0	8.0	21-2	2
3	Stripper w/ FC	FM 9058 F	2	4.0	2.90	79.6	30.1	7.1	82.2	7.5	21-2	1
3	Stripper w/ FC	FM 9058 F	3	3.7	2.90	81.0	28.3	7.2	82.8	7.8	21-1	2
3	Stripper w/ FC	FM 9063 B2RF	1	4.3	3.00	81.0	31.2	7.6	82.5	7.7	21-1	1
3	Stripper w/ FC	FM 9063 B2RF	2	3.8	3.00	80.7	31.0	7.8	83.6	7.6	11-2	2
3	Stripper w/ FC	FM 9063 B2RF	3	3.8	3.02	81.5	31.6	7.4	83.5	7.7	11-2	1
3	Stripper w/ FC	PHY 485 WRF	1	4.1	2.87	82.3	30.5	9.5	77.7	8.8	31-1	3
3	Stripper w/ FC	PHY 485 WRF	2	3.9	2.90	82.8	31.3	9.4	78.3	9.6	21-3	2

[a] UHML = upper-half mean length

Table 46 Continued.

Site	Treatment	Variety	Rep	Mic.	UHML[a] (cm)	Unif. (%)	Strength (g/tex)	Elong. (%)	Rd	+b	Color Grade	Leaf
3	Stripper w/ FC	PHY 485 WRF	3	4.0	2.92	83.7	29.5	9.9	76.2	8.9	31-3	3
3	Stripper w/ FC	ST 4554 B2RF	1	4.1	2.90	82.3	29.5	10.1	78.0	9.3	21-4	2
3	Stripper w/ FC	ST 4554 B2RF	2	3.7	2.87	81.6	29.6	9.9	77.0	9.7	21-4	2
3	Stripper w/ FC	ST 4554 B2RF	3	3.7	2.90	81.9	29.8	9.9	79.4	8.9	21-2	2
4	Picker	FM 9058 F	1	4.0	3.07	82.6	29.2	7.3	83.5	7.8	21-1	2
4	Picker	FM 9058 F	2	4.0	3.07	82.7	27.8	7.3	82.3	7.8	21-1	1
4	Picker	FM 9058 F	3	4.1	3.07	82.3	29.6	7.3	81.4	8.3	21-1	1
4	Picker	FM 9063 B2RF	1	4.2	3.10	81.8	30.9	7.6	82.8	7.5	21-1	1
4	Picker	FM 9063 B2RF	2	4.4	3.12	83.1	31.3	7.7	83.3	7.6	21-1	1
4	Picker	FM 9063 B2RF	3	4.4	3.12	83.2	30.3	7.9	81.6	7.7	21-1	1
4	Picker	PHY 485 WRF	1	4.0	2.84	82.6	27.2	9.8	77.9	9.2	21-2	2
4	Picker	PHY 485 WRF	2	4.5	2.87	83.8	28.3	10.0	76.1	9.6	31-3	1
4	Picker	PHY 485 WRF	3	4.0	2.92	83.0	28.0	10.1	76.5	9.4	31-3	2
4	Picker	ST 4554 B2RF	1	4.1	2.87	82.4	27.6	10.2	78.5	9.5	21-3	1
4	Picker	ST 4554 B2RF	2	4.4	2.87	82.3	27.4	10.2	78.8	9.4	21-3	1
4	Picker	ST 4554 B2RF	3	4.2	2.92	83.0	28.8	10.2	78.8	9.2	21-1	1
4	Stripper w/ FC	FM 9058 F	1	3.7	3.02	81.3	29.6	7.5	82.0	7.9	21-1	1
4	Stripper w/ FC	FM 9058 F	2	4.0	3.05	81.9	28.9	7.4	81.9	7.9	21-1	1
4	Stripper w/ FC	FM 9058 F	3	4.1	3.15	83.1	30.1	7.3	80.6	8.4	21-2	2
4	Stripper w/ FC	FM 9063 B2RF	1	4.1	3.02	81.9	30.1	7.9	83.9	7.8	11-1	1
4	Stripper w/ FC	FM 9063 B2RF	2	4.4	3.12	82.8	31.2	7.7	82.8	7.7	21-1	1
4	Stripper w/ FC	FM 9063 B2RF	3	4.5	3.10	83.1	30.7	7.7	82.6	7.7	21-1	1
4	Stripper w/ FC	PHY 485 WRF	1	3.9	2.82	82.4	28.4	9.8	76.9	9.4	21-4	2
4	Stripper w/ FC	PHY 485 WRF	2	4.4	2.87	82.8	27.7	10.1	75.5	9.5	31-3	3
4	Stripper w/ FC	PHY 485 WRF	3	3.9	2.92	84.1	29.4	9.9	75.4	9.7	32-1	3
4	Stripper w/ FC	ST 4554 B2RF	1	3.9	2.87	81.4	27.0	10.0	78.8	9.6	21-3	1
4	Stripper w/ FC	ST 4554 B2RF	2	4.1	2.90	82.3	28.1	10.1	76.7	10.4	22-1	2
4	Stripper w/ FC	ST 4554 B2RF	3	4.0	2.90	82.1	28.4	10.0	77.6	10.0	21-3	1

[a] UHML = upper-half mean length

APPENDIX G

AFIS ANALYSIS DATA

Table 47. AFIS data.

Site	Treatment	Variety	Rep	Nep Count (neps/g)	SFC[a] (% by weight)	VFM[b] (%)	IFC[c] (%)	Maturity Ratio
1	Picker	ST 4554 B2RF	1	460	13.7	0.89	11.1	0.81
1	Picker	ST 4554 B2RF	2	613	17.9	1.18	13.8	0.76
1	Picker	ST 4554 B2RF	3	564	15.8	1.01	12.4	0.78
1	Picker	ST 4554 B2RF	4	606	17	1.17	13.7	0.77
1	Stripper w/ FC	ST 4554 B2RF	1	664	16.4	1.17	13.1	0.78
1	Stripper w/ FC	ST 4554 B2RF	2	694	18.5	1.06	14.1	0.76
1	Stripper w/ FC	ST 4554 B2RF	3	624	17.4	1.18	14	0.78
1	Stripper w/ FC	ST 4554 B2RF	4	660	16.8	1.29	13.4	0.78
1	Stripper w/o FC	ST 4554 B2RF	1	706	18.1	1.13	13.6	0.77
1	Stripper w/o FC	ST 4554 B2RF	2	780	18.8	1.18	14.1	0.76
1	Stripper w/o FC	ST 4554 B2RF	3	772	18.4	1.44	15	0.75
1	Stripper w/o FC	ST 4554 B2RF	4	548	15.3	0.83	12.4	0.79
3	Picker	FM 9058 F	1	240	10.5	0.94	8.1	0.89
3	Picker	FM 9058 F	2	289	11.3	0.71	9.6	0.86
3	Picker	FM 9058 F	3	365	11.2	1.1	9.7	0.85
3	Picker	FM 9063 B2RF	1	266	10	1.04	9	0.86
3	Picker	FM 9063 B2RF	2	258	10.1	0.99	8.4	0.86
3	Picker	FM 9063 B2RF	3	342	9.1	0.66	8.7	0.86
3	Picker	PHY 485 WRF	1	275	10	2.14	7.5	0.84
3	Picker	PHY 485 WRF	2	330	9.8	2.45	7.7	0.84
3	Picker	PHY 485 WRF	3	289	9.9	2.4	8	0.85
3	Picker	ST 4554 B2RF	1	372	12.8	1.61	10	0.83
3	Picker	ST 4554 B2RF	2	346	12.7	1.35	10	0.82
3	Picker	ST 4554 B2RF	3	358	12.9	1.6	10	0.82
3	Stripper w/ FC	FM 9058 F	1	309	12.1	1.32	8.5	0.88
3	Stripper w/ FC	FM 9058 F	2	363	12.3	1.48	10	0.86
3	Stripper w/ FC	FM 9058 F	3	506	13.2	1.29	11.7	0.82
3	Stripper w/ FC	FM 9063 B2RF	1	314	10.1	1.51	9.2	0.86
3	Stripper w/ FC	FM 9063 B2RF	2	400	11.4	1.56	10.8	0.83
3	Stripper w/ FC	FM 9063 B2RF	3	414	11.5	1.56	11.5	0.82
3	Stripper w/ FC	PHY 485 WRF	1	347	10.2	3.53	8.5	0.83

[a] SFC = short fiber content

[b] VFM = visible foreign matter

[c] IFC = immature fiber content

Table 47 Continued.

Site	Treatment	Variety	Rep	Nep Count (neps/g)	SFC[a] (% by weight)	VFM[b] (%)	IFC[c] (%)	Maturity Ratio
3	Stripper w/ FC	PHY 485 WRF	2	438	9.5	3.21	8.8	0.83
3	Stripper w/ FC	PHY 485 WRF	3	332	9	3.71	8.3	0.84
3	Stripper w/ FC	ST 4554 B2RF	1	400	11.4	2.41	10	0.83
3	Stripper w/ FC	ST 4554 B2RF	2	464	12.8	2.85	11.3	0.81
3	Stripper w/ FC	ST 4554 B2RF	3	480	12.5	2.3	11.2	0.81
4	Picker	FM 9058 F	1	374	8.9	1.23	8.6	0.86
4	Picker	FM 9058 F	2	315	9.4	1.04	8.8	0.85
4	Picker	FM 9058 F	3	317	10.2	1.4	9	0.86
4	Picker	FM 9063 B2RF	1	268	8.4	0.67	8.5	0.86
4	Picker	FM 9063 B2RF	2	247	9.4	0.65	8.2	0.86
4	Picker	FM 9063 B2RF	3	226	7.9	0.74	8	0.88
4	Picker	PHY 485 WRF	1	371	10.9	2.09	8.5	0.82
4	Picker	PHY 485 WRF	2	282	9.6	2.49	6.8	0.85
4	Picker	PHY 485 WRF	3	339	10	2.78	8.3	0.82
4	Picker	ST 4554 B2RF	1	338	10.8	1.96	8.6	0.84
4	Picker	ST 4554 B2RF	2	304	10.7	1.48	8.4	0.84
4	Picker	ST 4554 B2RF	3	325	10.4	1.63	9.2	0.84
4	Stripper w/ FC	FM 9058 F	1	366	12.3	1.35	10	0.84
4	Stripper w/ FC	FM 9058 F	2	328	10.6	1.49	8.5	0.86
4	Stripper w/ FC	FM 9058 F	3	313	9.8	1.6	9.7	0.85
4	Stripper w/ FC	FM 9063 B2RF	1	338	9.3	1.28	8.8	0.85
4	Stripper w/ FC	FM 9063 B2RF	2	243	9.9	1.34	8.3	0.86
4	Stripper w/ FC	FM 9063 B2RF	3	244	8.5	1.63	7.6	0.87
4	Stripper w/ FC	PHY 485 WRF	1	359	10.3	3.53	8.9	0.83
4	Stripper w/ FC	PHY 485 WRF	2	364	9.9	3.68	8.3	0.83
4	Stripper w/ FC	PHY 485 WRF	3	400	9.4	4.67	8.9	0.83
4	Stripper w/ FC	ST 4554 B2RF	1	426	11.5	1.73	9.7	0.82
4	Stripper w/ FC	ST 4554 B2RF	2	350	10.7	1.89	8.9	0.84
4	Stripper w/ FC	ST 4554 B2RF	3	375	11.6	2.49	10	0.82

[a] SFC = short fiber content
[b] VFM = visible foreign matter
[c] IFC = immature fiber content

APPENDIX H

CARDED YARN DATA

Table 48. Carded yarn data.

Site	Treatment	Variety	Rep	CSP[a] (N-tex)	Elong. (%)	Ten. (cN/tex)	Work to Break (cN-cm)	CV (%)	Thin Places (cnt/km)	Thick Places (cnt/km)	Neps +200% (cnt/km)	Hairiness
1	Picker	ST 4554 B2RF	1	2796.7	7.56	11.71	358.84	22.45	563	1566	1461	4.58
1	Picker	ST 4554 B2RF	2	2858.6	8.11	12.29	399.39	23.00	661	1735	1701	4.79
1	Picker	ST 4554 B2RF	3	2926.6	7.69	11.35	357.18	22.68	594	1644	1506	4.87
1	Picker	ST 4554 B2RF	4	2909.2	7.85	12.20	390.54	22.56	571	1619	1501	4.75
1	Stripper w/ FC	ST 4554 B2RF	1	2785.6	7.77	11.90	374.68	23.20	677	1786	1597	5.15
1	Stripper w/ FC	ST 4554 B2RF	2	2817.1	8.04	11.39	368.73	23.99	854	1968	2028	5.14
1	Stripper w/ FC	ST 4554 B2RF	3	2906.3	7.96	11.68	378.26	23.37	734	1828	1841	5.05
1	Stripper w/ FC	ST 4554 B2RF	4	2901.3	7.88	12.45	399.75	23.17	703	1766	1684	4.98
1	Stripper w/o FC	ST 4554 B2RF	1	2636.5	7.62	11.72	360.09	23.79	830	1933	1921	5.14
1	Stripper w/o FC	ST 4554 B2RF	2	2827.1	8.03	12.19	396.35	23.31	712	1804	1750	5.18
1	Stripper w/o FC	ST 4554 B2RF	3	2790.8	7.87	11.68	372.82	23.80	876	1949	1983	5.39
1	Stripper w/o FC	ST 4554 B2RF	4	2987.1	7.97	12.17	398.51	22.37	529	1548	1488	4.95
3	Picker	FM 9058 F	1	3370.9	5.19	14.00	277.30	21.57	342	1374	1116	5.16
3	Picker	FM 9058 F	2	4061.6	5.74	15.21	331.44	19.95	190	991	801	4.88
3	Picker	FM 9058 F	3	3977.2	5.93	15.00	338.25	20.40	251	1077	883	4.97
3	Picker	FM 9063 B2RF	1	3887.8	6.01	15.64	355.60	19.91	188	969	753	4.54
3	Picker	FM 9063 B2RF	2	3721.1	5.91	14.86	332.45	19.98	194	978	750	4.76
3	Picker	FM 9063 B2RF	3	4035.9	6.21	15.56	360.65	19.68	179	907	755	4.65
3	Picker	PHY 485 WRF	1	3706.2	7.53	14.75	435.34	19.93	195	922	720	4.71
3	Picker	PHY 485 WRF	2	3881.1	7.55	14.95	446.28	19.80	175	919	703	4.51
3	Picker	PHY 485 WRF	3	3742.5	7.67	14.17	427.82	19.89	196	951	807	4.57
3	Picker	ST 4554 B2RF	1	3491.4	7.66	14.15	441.12	20.55	282	1096	905	4.92
3	Picker	ST 4554 B2RF	2	3452.4	7.18	13.62	401.28	20.78	280	1172	936	4.72
3	Picker	ST 4554 B2RF	3	3514.7	7.78	13.46	421.22	20.74	289	1154	997	4.88
3	Stripper w/ FC	FM 9058 F	1	3069.8	4.86	12.63	235.78	22.46	507	1570	1289	5.26
3	Stripper w/ FC	FM 9058 F	2	3868.4	5.16	14.10	284.34	20.66	252	1135	925	5.15
3	Stripper w/ FC	FM 9058 F	3	3839.7	5.72	14.67	320.84	20.88	282	1212	1119	5.11
3	Stripper w/ FC	FM 9063 B2RF	1	3826.6	5.80	15.33	335.88	20.07	186	999	814	4.69
3	Stripper w/ FC	FM 9063 B2RF	2	3771.8	5.88	14.77	327.48	20.09	207	1007	839	4.73
3	Stripper w/ FC	FM 9063 B2RF	3	4066.6	6.14	15.14	358.68	20.14	190	1038	857	4.82
3	Stripper w/ FC	PHY 485 WRF	1	3541.0	7.60	14.39	426.81	19.64	172	939	764	4.68

[a] CSP = count strength product

Table 48 Continued.

Site	Treatment	Variety	Rep	CSP[a] (N-tex)	Elong. (%)	Ten. (cN/tex)	Work to Break (cN-cm)	CV (%)	Thin Places (cnt/km)	Thick Places (cnt/km)	Neps +200% (cnt/km)	Hairiness
3	Stripper w/ FC	PHY 485 WRF	2	3733.0	7.01	14.35	407.90	19.79	177	964	777	4.83
3	Stripper w/ FC	PHY 485 WRF	3	3704.8	7.64	14.23	429.34	19.18	134	792	660	4.50
3	Stripper w/ FC	ST 4554 B2RF	1	3554.0	7.30	12.81	386.04	20.74	262	1166	1018	4.76
3	Stripper w/ FC	ST 4554 B2RF	2	3512.4	7.75	13.42	419.58	20.44	244	1089	1017	4.87
3	Stripper w/ FC	ST 4554 B2RF	3	3549.0	7.82	13.24	419.29	20.86	309	1185	1071	5.02
4	Picker	FM 9058 F	1	4172.3	6.10	15.16	353.29	18.99	119	772	568	4.65
4	Picker	FM 9058 F	2	4032.9	6.06	15.10	345.89	18.66	97	706	561	4.50
4	Picker	FM 9058 F	3	4255.0	6.08	15.79	364.21	18.68	99	717	535	4.48
4	Picker	FM 9063 B2RF	1	4006.9	6.43	15.51	373.85	18.84	94	752	510	4.63
4	Picker	FM 9063 B2RF	2	3952.1	6.13	14.75	348.12	19.11	125	795	576	4.58
4	Picker	FM 9063 B2RF	3	4109.5	6.01	14.70	346.78	19.19	137	782	540	4.46
4	Picker	PHY 485 WRF	1	3602.1	7.46	14.29	419.71	19.62	172	912	724	4.60
4	Picker	PHY 485 WRF	2	3774.7	7.73	13.85	436.16	19.39	182	822	654	4.39
4	Picker	PHY 485 WRF	3	3920.2	8.18	13.72	457.98	18.90	134	735	642	4.56
4	Picker	ST 4554 B2RF	1	3280.2	7.30	13.29	392.65	19.98	196	963	791	4.49
4	Picker	ST 4554 B2RF	2	3375.9	7.72	12.89	404.96	20.01	210	949	773	4.53
4	Picker	ST 4554 B2RF	3	3463.3	7.44	13.17	399.10	19.85	212	938	789	4.59
4	Stripper w/ FC	FM 9058 F	1	4221.2	5.94	15.54	360.77	19.49	150	868	651	4.82
4	Stripper w/ FC	FM 9058 F	2	4159.8	6.11	15.43	356.13	18.54	92	671	502	4.58
4	Stripper w/ FC	FM 9058 F	3	4064.7	5.95	15.18	341.09	19.28	148	868	702	4.64
4	Stripper w/ FC	FM 9063 B2RF	1	3924.2	6.27	14.80	358.25	19.06	121	803	601	4.52
4	Stripper w/ FC	FM 9063 B2RF	2	4105.6	6.42	14.67	364.59	19.06	131	780	533	4.59
4	Stripper w/ FC	FM 9063 B2RF	3	4103.5	6.22	15.48	372.75	18.94	109	713	487	4.61
4	Stripper w/ FC	PHY 485 WRF	1	3892.2	7.76	13.88	440.04	19.61	174	863	731	4.54
4	Stripper w/ FC	PHY 485 WRF	2	3369.7	7.70	13.57	419.24	19.50	167	859	717	4.35
4	Stripper w/ FC	PHY 485 WRF	3	3811.4	7.82	14.11	446.02	19.04	120	774	704	4.68
4	Stripper w/ FC	ST 4554 B2RF	1	3401.1	7.83	13.00	416.27	20.18	244	966	820	4.77
4	Stripper w/ FC	ST 4554 B2RF	2	3398.4	7.35	12.83	383.45	19.58	179	896	648	4.63
4	Stripper w/ FC	ST 4554 B2RF	3	3583.6	7.82	13.29	427.62	19.98	204	972	874	4.61

[a] CSP = count strength product

APPENDIX I

CARDED-AND-COMBED YARN DATA

Table 49. Carded-and-combed yarn data.

Site	Treatment	Variety	Rep	CSP[a] (N-tex)	Elong. (%)	Ten. (cN/tex)	Work to Break (cN-cm)	CV (%)	Thin Places (cnt/km)	Thick Places (cnt/km)	Neps +200% (cnt/km)	Hairiness
1	Picker	ST 4554 B2RF	1	3307.87	7.70	13.23	416.38	16.85	47	277	150	4.10
1	Picker	ST 4554 B2RF	2	3320.65	8.20	13.70	455.37	16.73	51	284	177	4.18
1	Picker	ST 4554 B2RF	3	3463.37	8.10	13.19	435.50	16.96	48	298	213	4.22
1	Picker	ST 4554 B2RF	4	3422.99	7.91	13.58	437.91	16.70	45	302	213	4.37
1	Stripper w/ FC	ST 4554 B2RF	1	3280.3	7.98	13.45	435.50	17.32	64	356	241	4.34
1	Stripper w/ FC	ST 4554 B2RF	2	3234.63	7.97	13.34	426.77	17.39	59	356	241	4.40
1	Stripper w/ FC	ST 4554 B2RF	3	3332.18	8.02	13.42	435.80	17.35	62	390	250	4.51
1	Stripper w/ FC	ST 4554 B2RF	4	3392.19	8.03	13.41	435.66	16.88	47	289	202	4.38
1	Stripper w/o FC	ST 4554 B2RF	1	3248.29	8.03	12.92	420.15	17.39	57	351	230	4.46
1	Stripper w/o FC	ST 4554 B2RF	2	3258.46	7.91	12.88	416.33	17.35	52	367	256	4.57
1	Stripper w/o FC	ST 4554 B2RF	3	3346.1	8.09	13.95	453.50	17.69	60	396	283	4.60
1	Stripper w/o FC	ST 4554 B2RF	4	3246.49	8.01	13.31	425.33	17.04	53	326	220	4.34
3	Picker	FM 9058 F	1	4402.30	5.40	15.80	317.35	15.22	17	125	51	4.44
3	Picker	FM 9058 F	2	4547.90	5.99	17.06	372.03	14.72	12	106	62	4.37
3	Picker	FM 9058 F	3	4177.73	6.05	16.93	365.39	14.85	14	111	69	4.49
3	Picker	FM 9063 B2RF	1	4641.20	6.24	15.89	375.10	14.99	15	102	58	4.32
3	Picker	FM 9063 B2RF	2	4716.62	6.43	16.82	404.48	14.84	15	96	57	4.31
3	Picker	FM 9063 B2RF	3	4737.06	6.67	17.25	426.14	14.83	12	107	72	4.16
3	Picker	PHY 485 WRF	1	4325.83	8.10	16.07	506.12	14.98	21	94	45	4.10
3	Picker	PHY 485 WRF	2	4237.97	7.81	15.85	473.69	15.06	20	101	55	4.07
3	Picker	PHY 485 WRF	3	4276.00	7.77	15.93	477.90	15.15	18	110	56	4.18
3	Picker	ST 4554 B2RF	1	3589.10	7.78	14.70	438.82	15.65	26	155	80	4.46
3	Picker	ST 4554 B2RF	2	3760.12	8.07	14.81	457.48	15.47	30	134	73	4.26
3	Picker	ST 4554 B2RF	3	3965.47	7.86	15.24	475.69	15.49	19	143	72	4.31
3	Stripper w/ FC	FM 9058 F	1	3709.38	5.12	14.82	278.70	15.80	20	168	75	4.64
3	Stripper w/ FC	FM 9058 F	2	4165.69	5.78	16.70	345.74	14.90	15	118	75	4.45
3	Stripper w/ FC	FM 9058 F	3	4403.80	6.01	17.08	375.26	15.03	10	123	81	4.60
3	Stripper w/ FC	FM 9063 B2RF	1	4237.77	6.18	16.68	376.68	15.24	18	127	65	4.23
3	Stripper w/ FC	FM 9063 B2RF	2	4314.10	6.13	16.53	369.48	15.21	17	122	67	4.33
3	Stripper w/ FC	FM 9063 B2RF	3	4516.73	6.48	17.55	420.71	15.05	16	113	69	4.36
3	Stripper w/ FC	PHY 485 WRF	1	4396.92	7.81	15.91	484.16	15.05	19	119	76	4.17

[a] CSP = count strength product

Table 49 Continued.

Site	Treatment	Variety	Rep	CSP[a] (N-tex)	Elong. (%)	Ten. (cN/tex)	Work to Break (cN-cm)	CV (%)	Thin Places (cnt/km)	Thick Places (cnt/km)	Neps +200% (cnt/km)	Hairiness
3	Stripper w/ FC	PHY 485 WRF	2	4389.22	7.94	16.04	494.74	15.06	17	125	85	4.05
3	Stripper w/ FC	PHY 485 WRF	3	4438.69	8.05	15.81	494.25	14.84	11	93	49	4.05
3	Stripper w/ FC	ST 4554 B2RF	1	3665.97	7.85	14.59	435.95	15.55	30	142	89	4.17
3	Stripper w/ FC	ST 4554 B2RF	2	3973.04	7.75	14.77	447.77	15.48	21	133	75	4.19
3	Stripper w/ FC	ST 4554 B2RF	3	3848.91	7.83	14.52	447.67	15.43	24	141	84	4.50
4	Picker	FM 9058 F	1	4557.70	6.26	16.99	388.21	14.39	7	73	39	4.03
4	Picker	FM 9058 F	2	4729.42	6.31	16.59	391.42	14.33	7	79	54	4.08
4	Picker	FM 9058 F	3	4483.78	6.13	17.09	386.73	14.56	10	92	53	4.32
4	Picker	FM 9063 B2RF	1	4548.52	6.66	16.59	414.63	14.64	10	87	45	4.16
4	Picker	FM 9063 B2RF	2	4239.53	6.54	16.48	398.90	14.93	11	113	48	4.27
4	Picker	FM 9063 B2RF	3	4657.58	6.53	16.62	412.01	14.62	13	83	40	3.99
4	Picker	PHY 485 WRF	1	4013.43	7.84	14.70	451.39	15.11	18	110	59	4.29
4	Picker	PHY 485 WRF	2	3816.33	7.83	14.65	447.48	15.15	20	111	61	4.29
4	Picker	PHY 485 WRF	3	4126.89	8.36	15.38	503.39	14.94	13	96	66	3.99
4	Picker	ST 4554 B2RF	1	3903.57	8.08	14.84	474.95	15.22	21	122	62	4.22
4	Picker	ST 4554 B2RF	2	3877.03	7.85	14.14	443.94	15.18	19	112	68	4.05
4	Picker	ST 4554 B2RF	3	3909.38	7.93	14.24	449.37	15.21	21	121	63	4.09
4	Stripper w/ FC	FM 9058 F	1	4753.05	6.36	17.17	406.20	14.45	9	87	52	4.21
4	Stripper w/ FC	FM 9058 F	2	4638.93	6.31	16.93	396.68	14.36	8	82	63	4.11
4	Stripper w/ FC	FM 9058 F	3	4480.15	6.20	17.18	389.82	14.61	8	87	55	4.33
4	Stripper w/ FC	FM 9063 B2RF	1	4383.86	6.71	16.47	407.11	14.60	12	93	61	4.05
4	Stripper w/ FC	FM 9063 B2RF	2	4243.49	6.45	16.74	401.81	14.84	15	96	50	4.26
4	Stripper w/ FC	FM 9063 B2RF	3	4416.72	6.46	16.29	393.59	14.65	13	83	44	4.26
4	Stripper w/ FC	PHY 485 WRF	1	4258.56	8.10	15.11	482.44	14.80	13	97	58	4.12
4	Stripper w/ FC	PHY 485 WRF	2	3924.02	7.84	14.63	445.21	15.26	20	121	77	4.21
4	Stripper w/ FC	PHY 485 WRF	3	4019.28	8.18	15.52	489.54	15.10	13	125	85	4.30
4	Stripper w/ FC	ST 4554 B2RF	1	3788.85	8.01	14.87	470.42	15.46	22	124	58	4.19
4	Stripper w/ FC	ST 4554 B2RF	2	3738.20	7.84	14.32	441.99	15.40	24	135	63	4.16
4	Stripper w/ FC	ST 4554 B2RF	3	3776.98	7.60	13.76	417.78	15.51	24	152	92	4.27

[a] CSP = count strength product

APPENDIX J

GLOSSARY

Card – textile equipment to clean and parallelize fibers for subsequent yarn formation

Count Strength Product – also known as *skein break factor*, a measure of yarn strength; the product of yarn count and the breaking load of a skein

Discount Rate – the rate used to discount future cash flows into their present values

Draft – the ratio of the sliver linear density before drawing to its linear density after drawing

Dust – foreign matter in cotton lint smaller than 500 μm

Elongation - the ratio of the extension of a fiber bundle or yarn during application of tension to the original length of the fiber bundle or yarn

Evenness – a measure of the cross-section mass variation in a given length of yarn

Field Efficiency – the percentage of time during harvest operations spent in the process of harvesting

Fineness – an indicator of fiber circumference, predominately affected by variety

Fractionation – the process used to separate lint and seeds from various classes of foreign matter in seed cotton

Hairiness – a relative indicator of the number of protrusions from the body of a yarn

Harvest Efficiency – a measure of the amount of seed cotton left in the field after harvest

Hulls – see *Burrs*

Immature Fiber – see *Maturity*

Leaf Grade – a visual estimate of the amount of leaf particles remaining in cotton lint

Length Uniformity – see *Uniformity Index*

Maturity – the degree of thickening of a fiber's secondary wall; a fiber is considered immature if the cell wall accounts for less than 25% of the cross-sectional area (Pierce and Lord, 1939)

Maturity Ratio - the ratio of the number of fibers with circularity values greater than 0.5 to the number of fibers with circularity values below 0.25, where circularity is the ratio of the cross-sectional area of a fiber to the area of a circle having the same perimeter

Micronaire – a measure of fiber fineness and maturity, conducted by measuring the resistance to airflow of a known mass of randomly oriented fibers

Motes – immature seeds

Nep – a tightly tangled mass of fibers; fiber neps may occur naturally in the boll, but nep counts are increased by mechanical processing; seed-coat neps are fragments of cottonseed that still have fibers attached to them

Net Present Value – a standard method for appraising the value of long-term projects

Noils – short fibers removed during the combing process

Reflectance (Rd) - a measure of the brightness of a sample of fibers

Roving – a loose assembly of fibers drawn into a single strand with very little twist

Scrapping Plate – a ribbed plate on the inside of a spindle-picker row unit intended to bring the cotton plant in closer proximity to the spindle drum

Short Fiber Content (SFC) – the percentage of cotton fibers shorter than 1.26 cm (0.5 inches)

Skein – a continuous strand of yarn

Skein Break Factor – see *Count Strength Product*

Staple – a measure of fiber length equivalent to 1/32 inch

Tenacity – a measure of the pressure required to break a fiber or yarn

Tex – the mass (in grams) of 1,000 m of fiber

Thick Places – the number of points in 1,000 m of yarn at which the yarn thickness is more than 50% the average thickness of the yarn

Thin Places – the number of points in 1,000 m of yarn at which the yarn thickness is less than 50% the average thickness of the yarn

Turnout – the ratio of the mass of lint produced to the mass of seed cotton ginned

Uniformity Index (UI) – the ratio between the mean fiber length and the upper-half mean fiber length

Upper-Half Mean Length (UHML) – the average length of the longest one-half of fibers

Upper Quartile Length (UQL) – the average length of the longest 25% of fibers

Yarn Count (Ne) – a measure of the linear density of yarn; the number of 840 yard skeins that can be made from a one pound hank of yarn

Yellowness (+b) – a measure of the degree of color pigmentation of cotton fibers

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