EVALUATION OF MODERN COTTON HARVEST SYSTEMS ON IRRIGATED COTTON: HARVESTER PERFORMANCE


ABSTRACT: Picker and stripper harvest systems were evaluated on production-scale irrigated cotton on the High Plains of Texas over three harvest seasons. Observations on harvester performance, including time-in-motion, harvest loss, seed cotton composition, and turnout, were conducted at seven locations with multiple cultivars. In systems where sufficient support equipment was available, strippers had higher productivity (i.e. acres per hour) than pickers. In higher yielding cotton, pickers had a higher productivity rate than strippers. The picker harvest had higher harvest losses but also resulted in lower levels of foreign matter and, therefore, higher turnout. The results of this research have elsewhere been incorporated into an economic model comparing harvest systems under various yield conditions.

Keywords. Cotton, Harvester, Picker, Stripper, Time-in-motion, Harvest loss.

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. In recent years, Texas cotton production has represented almost half of all U.S. production. Owing to the harsh weather conditions of the region, most of the cotton on the High Plains is of more storm-proof cultivars that have traditionally been harvested with stripper harvesters.

Unlike picker harvesters, which use spindles to remove seed cotton from the boll of the plant, stripper harvesters use brushes and paddles to remove seed cotton. As a result, stripper harvested cotton contains more foreign matter (burrs, leaves, and many branches from the stem of the plant) 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. Stripper harvesters also have the potential to harvest more immature bolls than a picker harvester. These immature bolls can lead to lower micronaire values and lower yarn strength, which can adversely affect spinning performance at the textile mill and may affect dye uptake.

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, collect less foreign material, are perceived to maintain fiber quality characteristics better than strippers, and may be able to harvest cotton at higher speeds in high yielding stands.

As irrigation technology has improved and new cotton cultivars 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/acre). It is estimated that around 120,000 ha (300,000 acres) of sub-surface drip irrigation has been installed on the High Plains in the past 10 years for cotton production and over 450,000 ha (1.1 million acres) 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.

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.

The objective of this research is to compare picker and stripper cotton harvesters in irrigated cotton on the High Plains of Texas based on:

- the time spent in each segment of harvest operations (i.e. time-in-motion),
- harvest losses (i.e. amount of seed cotton left in the field),
- foreign matter content of seed cotton, and
- gin turnout.
Each of these factors is a critical component in evaluating the productivity and profitability of a harvest system.

**LITERATURE REVIEW**

**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, unloading 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 bolls open. 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 picker 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%.

**HARVEST LOSS**

Harvest loss 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 higher harvest losses, but the gains in labor efficiency have far surpassed the losses in harvest efficiency, resulting in complete conversion of the U.S. cotton industry to mechanical harvesters. Because stripper harvesters are less discriminating than picker harvesters, it would be expected that stripper harvesters would have lower harvest losses. 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%. The physical characteristics of the boll and plant can dramatically impact harvest losses during picking. Corley (1966) measured picking efficiencies of 95% for fluffy bolls compared to 90% and 65% for weathered (receiving 102 mm of rain) and knotty (containing hard locks) bolls, respectively. Tupper (1966) reported picking efficiencies of 88% on a more storm-proof variety of cotton compared to 94% for a less tight-locked variety. Stripping efficiencies on these same varieties were 96% and 95%, respectively (Tupper, 1966). While stripper harvesters may have lower harvest losses, the cotton left unharvested by a spindle picker is often less mature, having lower micronaire values and subsequently being weaker. Increases in harvest losses can be the result of cotton being left on the plant or being knocked off the plant onto the ground (Kepner et al., 1978). 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 cultivars of cotton harvested with a two-row spindle picker (John Deere 9910, Des Moines, Iowa) and a four-row brush-roller stripper (John Deere 7445, Des Moines, Iowa) with and without a field cleaner. Cultivars tested include Paymaster HS26 (considered a “stripper cultivar”) and Stoneville 132 (an early maturing “picker cultivar”). Significant differences were found between the yield of seed cotton and lint 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 cultivar. 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 cultivars 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 5 bales/ha (2 bales/acre), further limiting application of the results of this study to new cultivars 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 lint, 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 bats) does not represent modern harvesting machinery. And again, the yields in this study were all below 5 bales/ha (2 bales/acre).

Faircloth et al. (2004) did a more comprehensive comparison of harvest methods on irrigated cotton in northeast Louisiana, looking at several cultivars. 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 cultivar. 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/acre), with the highest reported yield being 6.7 bales/ha (2.7 bales/acre) 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/acre) in year one and...
6.4 bales/ha (2.6 bale/acre) 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.

It should be noted that harvest losses and gin turnout are often related, as harvesters with low harvest losses often introduce more foreign matter into seed cotton taken to the gin. The greater foreign matter content subsequently requires more aggressive cleaning, which can also lead to losses of marketable fibers.

FRACTIONATION

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. Non-field-cleaned stripped cotton typically has approximately 320 kg (700 lb) of foreign matter per bale compared to 45 kg (100 lb) for picked cotton (table 1). Stripped cotton that has been field-cleaned typically has approximately 180 kg (400 lb) of foreign matter per bale.

LINT TURNOUT

Lint 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 cultivar (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% for non-field-cleaned cotton. Based on recent observations, field cleaned cotton may generate turnouts ranging from 25% to 35%, but it is expected that picked cotton will have a higher lint turnout than stripped and field cleaned cotton of the same cultivar harvested under similar conditions. Results of other research have demonstrated similar results (Watson, 1951; Corley and Stokes, 1964; Kirk et al., 1969).

METHODS

Field work was conducted in a total of nine fields at seven different sites on the High Plains from 2006 to 2008. When possible, time-in-motion studies were conducted while harvesting on a typical field scale. Most of the seed cotton sampling and harvest loss tests occurred while harvesting smaller plots. Observations were made with a six-row John Deere 9996 picker harvester with Pro-16 row units and various John Deere brush strippers, including 7460 models with field cleaners and a 7450 model without a field cleaner. All stripper harvesters were provided by producer-cooperators.

SITE DESCRIPTIONS

Site 1

In 2006, sampling was conducted at a field approximately 24 km (15 miles) west of Plains, Texas, in Yoakum County. The field was located on a Brownfield fine sand, and Stoneville 4554 Bollgard II® Roundup Ready Flex® (ST 4554 B2RF; Bayer CropScience, Research Triangle Park, N.C.) 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/acre). A John Deere 9996 picker was operated by employees of the producer and was equipped with scarping plates on both front and rear drums. A John Deere 7460 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.

Hand-picked 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 Standards, 2006). 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 ginning, fiber quality, and spinning tests. Fiber and yarn quality tests are described by Faulkner et al. (2011a, 2011b).

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 a commercial gin 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 loss tests. For the picker, additional time-in-motion data were collected in the remainder of the field. 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 (4 miles) east of Wilson, Texas, in Lynn County. The field was located on an Amarillo loam, and FiberMax 9063 Bollgard II® Roundup Ready Flex® (FM 9063 B2F, Bayer CropScience, Research Triangle Park, N.C.) 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/acre). A John Deere 9996 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 John Deere 7460 stripper was operated by the producer-cooperator a week after picking.

Harvest loss and moisture content samples were collected, and detailed time-in-motion and plant height data were recorded for the picker at Site 2. Plant height data were collected by measuring the distance from the cotyledon to the terminal node of ten plants in five different plots.

One Sam Stevens boll buggy and one module builder were included in each harvest system with a single harvester. 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 (11 miles) north-west of Muleshoe, Texas, in Parmer County. 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 loss tests were conducted and fiber samples were collected from the first field, which was used for cropping systems trials. Four cultivars were included in the harvester comparison study, including FiberMax 9058 Flex® (FM 9058 F, Bayer CropScience, Research Triangle Park, N.C.), FM 9063 B2F, PhytoGen 485 Widerstrike Roundup Ready Flex) (PHY 485 WRF, Bayer CropScience, Research Triangle Park, N.C.), and ST 4554 B2RF. The field was planted in a randomized complete block fashion with three replications for each cultivar (fig. 1). 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 remaining six rows of each plot were harvested with a six-row stripper with a field cleaner. The side of the plot that was picked was randomly selected for each plot. A John Deere 9996 picker (Des Moines, Iowa) was operated by TAMU personnel and was equipped with scrapping plates on the rear drums. A John Deere 7460 stripper (Des Moines, Iowa) was operated by a custom harvester provided by the producer-cooperator.

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. 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. Plant height data were also collected from each plot for each harvest treatment. 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 ginning, fiber quality, and spinning tests. (Fiber and yarn quality test results are not included in this article.)

Time-in-motion data were collected from a second field at Site 3 planted in FiberMax 960 Bollgard II® Roundup Ready (FM 960 B2R; Bayer CropScience, Research Triangle Park, N.C.). The field was planted in a circular fashion due to use of a Low Energy Precision Application (LEPA) irrigation system and had an average yield of 6.2 bales/ha (2.5 bales/acre). 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. GPS integrated with the time-in-motion data recording program were used to determine row lengths and the area harvested per basket unloading cycle.

**Site 4**

The third site where sampling was conducted in 2007 included two fields approximately 19 km (12 miles) east of Plains, Texas, in Yoakum County. 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 loss tests were conducted and fiber samples collected from the first field, which was used for systems trials. The same four cultivars 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 cultivar (fig. 2). 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 remaining six rows of each plot were harvested with a six-row stripper with a field cleaner. The side of the plot that was picked was randomly selected for each plot. A John Deere 9996 picker was operated by TAMU personnel and was equipped with scrapping plates on the rear drums. A John Deere 7460 stripper was operated by employees of the producer-cooperator.

Sampling at Site 4 was conducted in a similar manner to Site 3.

Time-in-motion data were collected from a second field at Site 4 planted in FiberMax 955 LibertyLink® Bollgard II® (FM 955 LLB2; Bayer CropScience, Research Triangle Park, N.C.). Cotton was planted beyond the edge of the area
irrigated by the center pivot system, but most of the field was irrigated. The field average yield was 8.15 bales/ha (3.3 bales/acre). 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. GPS integrated with the time-in-motion data recording program were used to determine row lengths and the area harvested per basket unloading cycle.

**Site 5**

In 2008, sampling was conducted at three sites. The first site was a field approximately 4 km (2 miles) north of Ralls, Texas, in Crosby County. The field was located on a Pullman silty clay loam, and FiberMax 9180 Bollgard II® Roundup Ready Flex (FM 9180 B2F; Bayer CropScience, Research Triangle Park, N.C.) was planted on 102-cm (40-in.) centers. Cotton was irrigated with a sub-surface drip irrigation system and had an average yield of 9.44 bales/ha (3.82 bales/acre). A John Deere 9996 picker was operated by TAMU personnel and was equipped with scrapping plates on the rear drums only. An eight-row John Deere 7460 stripper with field cleaner was operated by the producer-cooperator. Plots were organized in a randomized complete block design with replication as the blocking factor. Two harvest treatments were used including picking and stripping. Harvest loss, time-in-motion, plant height, and moisture content data were collected along with samples for fiber quality and spinning tests. The GPS system for time-in-motion analysis on the picker malfunctioned such that accurate harvester speed data was not collected.

**Site 6**

The second site harvested in 2008 was a field approximately 17 km (11 miles) northwest of Muleshoe, Texas, in Parmer County. The field was located on an Acuff loam, and FiberMax 9150 Roundup Ready Flex (FM 9150 F, Bayer CropScience, Research Triangle Park, N.C.) was planted on 76-cm (30-in.) centers into corn stubble. Cotton was irrigated with a low-energy precision application (LEPA) center pivot irrigation system and had an average yield of 5.62 bales/ha (2.27 bales/acre). A John Deere 9996 picker was operated by TAMU personnel and was equipped with scrapping plates on the rear drums only. A six-row John Deere 7450 stripper with no field cleaner was operated by the producer-cooperator. The cotton at Site 6 was terminated by an early freeze before many of the bolls had opened. This resulted in lower-than-normal harvest efficiencies for the picker and extremely low micronaire values (Faulkner, 2011a).

As at Site 5, plots were organized in a randomized complete block design with replication as the blocking factor. Two harvest treatments were used including picking and stripping. Harvest loss, time-in-motion, plant height, and moisture content data were collected along with samples for fiber quality and spinning tests. Time-in-motion data for the stripper harvester at Site 7 was corrupted before analysis.

**TIME-IN-MOTION**

Time-in-motion data were collected for each harvest system by an observer riding in the cab of the harvester at each site. A macro in Microsoft Excel (Redmond, Wash.) 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 transfers made into each module by the number of bales produced from each module at the gin.
**Harvest Loss**

Harvest loss tests were conducted to determine the amount of seed cotton left in the field by each harvester. Before mechanical harvesting, a location within each experimental plot was randomly selected and marked (fig. 3). (Care was taken to avoid wheel-tracks of center pivot systems within the 7.5-m sample row.) 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 loss of the mechanical harvester by assuming that the yields in both 3.0-m (10-ft) 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 (stalk loss), and any cotton lying on the ground was also collected separately (drop loss).

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

\[
L = \left( \frac{P + G}{H} \right) \times 100\%
\]

where
- \(L\) = harvest loss (%),
- \(P\) = 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.

**Foreign Matter Content**

At most field sites, 1.0-kg samples for fractionation analysis were collected from a weigh wagon for each replication of each harvest-method-by-cultivar combination. For each sample, foreign matter in the seed cotton was determined using 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, N.J.) with a 0.1-g resolution.

**Lint Turnout**

In 2006, lint turnout for seed cotton from each harvest method at Site 1 was measured from the full-size modules ginned at a commercial gin. Because only one module was produced with each harvest method, no statistical analysis was conducted on 2006 turnout data. In 2007 and 2008, lint and seed turnout were measured from the samples ginned at the USDA-ARS Cotton Production and Processing Research Unit. All samples underwent similar pre-cleaning regimes, including:
- suction/green boll separator,
- feed control,
- drier #1 (no heat was added),
- incline cleaner (6 cylinders),
- combination burr and stick machine (#1 extractor),
- drier #2 (no heat was added),
- incline cleaner (6 cylinders),
- stick machine (#2 extractor), and
- extractor feeder/93 saw gin stand.

In 2006 and 2007, all samples underwent one stage of lint cleaning. In 2008, a large number of samples from the High Plains region had bark contamination, necessitating more cleaning, so all samples in 2008 underwent two stages of lint cleaning. The mass of seedcotton and corresponding lint and seed were measured for each sample and the turnout was determined.

**Statistical Analysis**

For each of the aforementioned parameters, harvest treatments were compared using the General Linear Model function in SPSS (SPSS 14.0, SPSS Inc., Chicago, Ill.) with the null hypothesis (\(\alpha = 0.05\)) that the means from all harvest treatments were equal. Means were compared with the Least Significant Difference (LSD) pair-wise multiple comparison test. In addition, correlations between harvest loss and plant height, as well as harvest loss and seed cotton moisture content, were analyzed 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. The “Unload Time” column indicates the interval between the beginning of the basket unloading process and resuming harvest. It does not account for the amount of time spent waiting for a boll buggy to position near the harvester. Due to the number of covariates, time-in-motion data did not lend themselves to statistical analysis.

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 unloading mechanism on the stripper compared to a floor chain transfer system on the larger picker basket. The time spent transferring cotton at all locations was highly dependent on the availability of boll buggies and module builders that were prepared to receive cotton when the boll buggies reached the turn row.

At most locations the boll buggies were able to take three basket transfers from the stripper before unloading into the module builder, but they were only able to receive one basket transfer from the picker. Because the boll buggies at Site 3 were not equipped with a hydraulic vane packer, transferring from the picker into the boll buggy took substantially longer as 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 total time spent in activities other than harvesting (e.g., waiting for a boll buggy, transferring cotton, turning at the end of a row) was most significantly impacted by the

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**Figure 3.** Schematic of harvest loss test plots.
Table 2. Time-in-motion data.

<table>
<thead>
<tr>
<th>Harvester</th>
<th>Location</th>
<th>Rows per Harvester Pass</th>
<th>Yield [bales/ha (bales/acre)]</th>
<th>Speed [km/h (mph)]</th>
<th>Basket Capacity (bales)</th>
<th>Unload Time[a] (s)</th>
<th>Turn at End of Row (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picker</td>
<td>Site 1</td>
<td>6</td>
<td>5.4 (2.2)</td>
<td>6.4 (4.0)</td>
<td>--</td>
<td>77</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Site 2</td>
<td>6</td>
<td>9.1 (3.7)</td>
<td>6.0 (3.7)</td>
<td>4.60</td>
<td>49</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Site 3</td>
<td>6</td>
<td>6.2 (2.5)</td>
<td>7.7 (4.8)[b]</td>
<td>3.99</td>
<td>104</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>Site 4</td>
<td>6</td>
<td>8.1 (3.3)</td>
<td>5.8 (3.6)</td>
<td>5.85</td>
<td>--</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>Site 5</td>
<td>6</td>
<td>9.4 (3.8)</td>
<td>4.6 (2.8)[c]</td>
<td>4.67</td>
<td>47</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Site 6</td>
<td>6</td>
<td>5.6 (2.3) --</td>
<td>4.57</td>
<td>48</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Site 7</td>
<td>6</td>
<td>5.6 (2.3)</td>
<td>5.9 (3.7)</td>
<td>4.42</td>
<td>--</td>
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<tr>
<td>Avg.</td>
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<td></td>
<td>4.68</td>
<td>65</td>
<td>36</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

S. w/ FC[d]

| Site 1   | 6                       | 4.9 (2.0)                      | 6.0 (3.7)         | 1.98               | 54                       | 27                  |
| Site 2   | 8                       | 9.1 (3.7)                      | 4.5 (2.8)[c]      | --                 | --                       | --                  |
| Site 4   | 6                       | 8.1 (3.3)                      | 4.8 (3.0)         | 2.26               | 36                       | 36                  |
| Site 5   | 8                       | 9.4 (3.8)                      | 2.9 (1.8)[c]      | 2.22               | 27                       | 31                  |
| Site 7   | 6                       | 5.6 (2.3) --                   | 1.73              | --                 | --                       | --                  |
| Avg.      |          |                         | 2.05                           | 39                | 31                       |                     |

S. w/o FC[f]

| Site 1   | 6                       | 5.9 (2.4)                      | 5.5 (3.4)         | 1.79               | 54                       | 31                  |
| Site 3   | 6                       | 6.2 (2.5)                      | 8.9 (5.5)[b]      | 1.79               | 20                       | 27                  |
| Site 6   | 6                       | 5.6 (2.3)                      | 5.7 (3.5)         | 1.27[d]            | 40                       | 41                  |
| Avg.      |          |                         | 1.79/1.27[d]        | 38                | 33                       |                     |

[a] Unload time indicates the interval between the beginning of the basket unloading process and resuming harvest. It does not account for the amount of time spent waiting for a boll buggy to service the harvester.

[b] Harvested in 2nd gear.

[c] Harvest speed reduced due to an engine component failure resulting in power loss.

[d] S. w/FC = stripper with field cleaner.

[e] Data from 8‐row stripper with field cleaner.

[f] S. w/o FC = stripper without field cleaner.

[g] Site 6 was harvested with a John Deere 7450 stripper, which did not have a packing vane in the basket.

number of boll buggies and module builders operating in the field. For example, at Site 5, when only one boll buggy was operating, the total time between stopping harvest to unload into the boll buggy and resuming harvest was 137 s, compared to 73 s when two boll buggies were operating. Similarly, at Site 3, when one module builder was used to receive cotton from a harvester, the harvester spent substantially more time, on average, waiting for a boll buggy than when two module builders were available because the full boll buggy was unable to dump during the time that the single module builder was finishing a module.

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 six‐row harvesters, no harvester down time, and 915‐m (3000‐ft) rows planted on 76‐cm (30‐in.) centers. Average harvester basket capacities and transfer times from table 2 were assumed. For all harvesters, an interval of 55 s per basket unloading cycle was assumed to account for the time required for a boll buggy to position for receiving a basket dump after the harvester stops in the field. This 55‐s interval represents the average from all sites in which boll buggy capacity was not the bottleneck in harvest operations. At some sites, a much shorter interval was required for the boll buggy to position for receiving cotton, but at these sites, the boll buggy operator closely trailed the harvesters, increasing diesel consumption and equipment wear.

Harvester speed was estimated based on measured data. 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 33 s was assumed for all harvesters. The results shown in table 3 represent a maximum theoretical productivity level as down time was not considered in the analysis, and the time spent waiting for a boll buggy assumes that sufficient support machinery is available to prevent long wait times for boll buggies to position during a basket unloading cycle.

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

<table>
<thead>
<tr>
<th></th>
<th>Picker</th>
<th>Stripper w/FC</th>
<th>Stripper w/o FC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>7.7 (4.8)</td>
<td>8.9 (5.5)</td>
<td>8.9 (5.5)</td>
</tr>
<tr>
<td>Productivity [ha/h (acre/h)]</td>
<td>3.01 (7.46)</td>
<td>3.15 (7.81)</td>
<td>3.09 (7.63)</td>
</tr>
<tr>
<td>Harvesting (%)</td>
<td>85.4</td>
<td>78.1</td>
<td>76.5</td>
</tr>
<tr>
<td>Transferring (%)</td>
<td>8.1</td>
<td>15.0</td>
<td>16.7</td>
</tr>
<tr>
<td>Turning (%)</td>
<td>6.6</td>
<td>6.9</td>
<td>6.8</td>
</tr>
<tr>
<td>Turn at End of Row (%)</td>
<td>7.4 bales/ha (3.0 bales/acre)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td>6.1 (3.8)</td>
<td>4.8 (3.0)</td>
<td>5.1 (3.2)</td>
</tr>
<tr>
<td>Productivity [ha/h (acre/h)]</td>
<td>2.31 (5.71)</td>
<td>1.75 (4.33)</td>
<td>1.80 (4.44)</td>
</tr>
<tr>
<td>Harvesting (%)</td>
<td>82.7</td>
<td>79.6</td>
<td>76.6</td>
</tr>
<tr>
<td>Transferring (%)</td>
<td>12.3</td>
<td>16.6</td>
<td>19.5</td>
</tr>
<tr>
<td>Turning (%)</td>
<td>5.0</td>
<td>3.8</td>
<td>3.9</td>
</tr>
<tr>
<td>Turn at End of Row (%)</td>
<td>9.9 bales/ha (4.0 bales/acre)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Speed</td>
<td>5.1 (3.2)</td>
<td>3.9 (2.4)</td>
<td>4.2 (2.6)</td>
</tr>
<tr>
<td>Productivity [ha/h (acre/h)]</td>
<td>1.93 (4.76)</td>
<td>1.40 (3.45)</td>
<td>1.45 (3.58)</td>
</tr>
<tr>
<td>Harvesting (%)</td>
<td>82.2</td>
<td>79.3</td>
<td>75.9</td>
</tr>
<tr>
<td>Transferring (%)</td>
<td>13.6</td>
<td>17.6</td>
<td>20.9</td>
</tr>
<tr>
<td>Turning (%)</td>
<td>4.2</td>
<td>3.1</td>
<td>3.2</td>
</tr>
</tbody>
</table>

[a] Simulation assumes no harvester downtime and a 55‐s interval for the boll buggy to position during each basket unloading cycle.
In general, the picker was able to harvest a unit area of cotton more quickly than was either stripper harvester in high-yielding stands due to the larger basket capacity. 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 picker was able to harvest at a faster rate than the picker, giving it an advantage in terms of area harvested per unit time. Even though the picker is predicted to spend a greater percentage of the time harvesting than either stripper harvester in 3.7-bale/ha (1.5-bale/acre) cotton, the lower harvest speed results in lower productivity for the picker harvester in terms of area per unit time. The field efficiencies (i.e., percent of time spent harvesting) reported in table 3 are higher than reported by Willcutt and Barnes (2008), but, again, the values in table 3 represent a theoretical maximum field efficiency.

**Harvest Loss**

Correlations between harvest loss and plant height, as well as hand-picked seed cotton moisture content, were analyzed using Pearson’s two-tailed correlation tests. Plant height data were not collected at Site 1. No correlation was detected between plant height and total loss, but a significant correlation (p = 0.010) was detected between moisture content and harvest loss with a correlation coefficient of 0.312. Average plant heights and moisture contents are shown in table 4.

No statistical differences in plant height or moisture content at any given location were detected with the exception of FM 9063 B2F plots at Site 4, for which the moisture content of the picked cotton (4.63% db) was lower (p = 0.041) than the stripped cotton (5.66% db), and the FM 9180 plots at Site 7 (p = 0.024). Given the similarity in management practices and soil type combined with the lack of differences in all other cultivars, the difference in moisture content between picked and stripped treatments of FM 9063 B2F at Site 4 and FM 9180 B2F at Site 7 would likely disappear with a greater sample population.

Based on between-subject effects, harvest loss varied by harvester treatment (p < 0.0005) but not by cultivar or harvest location (α = 0.05). Overall harvest losses are shown in table 5.

For a given harvest method, no differences were detected in harvest loss between cultivars 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 unharvested seed cotton.

At Site 5, samples were collected from the burr trail of the field cleaner. On average, 0.25% of the cotton harvested was ejected by the field cleaner into the burr trail. No formal analysis was conducted on the maturity of the seed cotton collected from the burr trail, but visual observations indicate that most of this cotton was contained in only slightly cracked bolls. Therefore, the fibers left in the burr trail were likely immature and not suitable for spinning.

**Foreign Matter Content**

Significant differences in foreign matter content were detected using Roy’s Largest Root multivariate analysis of variance (MANOVA) by cultivar (p = 0.001) and treatment (p < 0.0005). Between-subject effects by cultivar were detected in the percent of sticks (p = 0.007) and fine trash (p = 0.017). Between-subject effects by treatment were significant (α = 0.05) for all fractionation results except grass (p = 0.782) and motes (p = 0.538). The average composition of seed cotton across all sites from each harvester treatment as determined by fractionation analysis is shown in table 6.

The percent of burrs, sticks, and total foreign material was higher for the stripper without field cleaner than the stripper with field cleaner (p < 0.0005 for all). The amount of foreign material of all classes in seed cotton, with the exception of pin trash, was higher for the stripper without the field cleaner than the spindle picker (p < 0.005 for all except pin trash). Spindle picked seed cotton had a lower percentage of hulls, sticks, leaf, pin trash, and total foreign material than the seed cotton that was stripped and field cleaned (p < 0.0005 for all).

**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.

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Table 5. Average harvest losses.[a]

<table>
<thead>
<tr>
<th>Harvest Method</th>
<th>Losses (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picker</td>
<td>6.8 ±0.8 x</td>
</tr>
<tr>
<td>Stripper w/field cleaner</td>
<td>2.0 ±0.8 y</td>
</tr>
<tr>
<td>Stripper w/o field cleaner</td>
<td>1.3 ±1.8 y</td>
</tr>
</tbody>
</table>

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

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Table 4. Average plant height and moisture content of seed cotton during harvest.

<table>
<thead>
<tr>
<th>Location</th>
<th>Plant Height (cm)</th>
<th>Moisture Content (%db)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Picked</td>
<td>Stripped w/o FC[a]</td>
</tr>
<tr>
<td>Site 1</td>
<td>--</td>
<td>96.6 ±6.3</td>
</tr>
<tr>
<td>Site 2</td>
<td>72.0</td>
<td>--</td>
</tr>
<tr>
<td>Site 3</td>
<td>57.5</td>
<td>--</td>
</tr>
<tr>
<td>Site 4</td>
<td>80.1</td>
<td>79.6 ±5.7</td>
</tr>
<tr>
<td>Site 5</td>
<td>76.5</td>
<td>71.9 ±2.9</td>
</tr>
<tr>
<td>Site 6</td>
<td>64.8</td>
<td>61.2 ±7.2</td>
</tr>
<tr>
<td>Site 7</td>
<td>63.7</td>
<td>63.7 ±6.8</td>
</tr>
</tbody>
</table>

[a] FC = field cleaner.

---

Table 6. Percent composition of harvested material.[a]

<table>
<thead>
<tr>
<th>Harvest Method</th>
<th>Stripped w/F[a]</th>
<th>Stripped w/o FC[b]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lint and seeds</td>
<td>94.4 x</td>
<td>80.9 y</td>
</tr>
<tr>
<td>Total foreign material</td>
<td>5.13 x</td>
<td>19.0 y</td>
</tr>
<tr>
<td>Burrs</td>
<td>1.9 x</td>
<td>9.9 y</td>
</tr>
<tr>
<td>Sticks</td>
<td>0.6 x</td>
<td>3.6 y</td>
</tr>
<tr>
<td>Leaf</td>
<td>1.8 x</td>
<td>4.1 y</td>
</tr>
<tr>
<td>Pin trash</td>
<td>0.7 x</td>
<td>1.3 y</td>
</tr>
</tbody>
</table>

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

[b] FC = field cleaner (also known as a burr extractor).
Significant differences were detected in lint turnout from cotton harvested at Sites 3, 4, 5, and 7 by cultivar (p < 0.0005), treatment (p < 0.0005), and the interaction between location and treatment (p = 0.003). Average lint turnouts for each cultivar and harvest treatment for Sites 3, 4, 5, and 7 are shown in Table 8. Data from Site 6 were excluded from this analysis due to the low percentage of open bolls that resulted from early termination by freezing weather. For each cultivar, the lint turnout of stripped cotton was significantly lower than that of 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.

For all sites, turnout of picked cotton was higher than predicted by Williford et al. (1994), although on average, the turnout of PHY 485 WRF was slightly lower. For all sites and cultivars, the turnout of field-cleaned cotton was higher than predicted by Williford et al. (1994). The turnout of non-field cleaned, stripped cotton was slightly higher than predicted by Williford et al. (1994) in 2006 but not in 2008 when the cotton was terminated by an early freeze. Improvements in lint turnout may result of improved harvester performance, varietal differences, differences in location, or a combination of these factors.

Seed turnout varied by harvest treatment (p < 0.0005) and location-treatment interaction (p = 0.035). The average seed turnout for picked samples was 54.9% compared to 45.4% from stripped and field cleaned samples. The average weight of seed per 220-kg (480-lb) bale varied significantly (p < 0.0005) by cultivar only (Table 9). The variation in seed weight per bale explains the differences in lint turnout as function of cultivar for a given harvest treatment.

### Conclusions

Harvester performance, fiber quality, and harvest system costs are important considerations when comparing cotton harvesting systems. Harvester performance was measured as a function of time-in-motion, harvest loss, foreign matter content of seed cotton, and lint turnout at the gin at seven irrigated sites on the High Plains of Texas. The results of this research were elsewhere used to conduct an economic comparison of picker and stripper harvesting systems (Faulkner et al., 2011c).

Time-in-motion performance was highly dependent on equipment used in the harvest system and machinery operators. In systems where sufficient support equipment such as boll buggies and module builders were available, strippers had higher productivity (i.e. acres per hour) than pickers in lower yielding cotton in spite of the fact that stripper harvesters have smaller basket capacity than pickers, requiring more frequent transfer of cotton from the harvester basket. In higher yielding cotton, pickers had a higher productivity rate than strippers.

The John Deere 9996 picker was shown to have statistically higher higher harvest losses than the John Deere 7450 and 7460 strippers regardless of cultivar 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.

As expected, the foreign matter content of picked cotton was significantly lower than that of stripped cotton, and field cleaned cotton contained less foreign matter than non-field cleaned cotton. While the field cleaner reduced the percentage of hulls and stick in the seed cotton, leaf content was unchanged and pin trash increased. The reduced foreign matter content in the picked cotton also led to greater lint turnout, as would be expected. Turnout also varied significantly by cultivar.

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### References


